# CARNEGIE SCIENCE

2018-2019 YEAR BOOK

CARNEGIE SCIENCE

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May 1, 2020

Dear Friend,

During these unprecedented times, I am more grateful than ever for your support of Carnegie Science and our mission of investigation, research, and discovery in the service of humanity.

When we began compiling this annual report, we could not have anticipated the current circumstances. Yet, as I review this year's scientific accomplishments, I am reminded that the Carnegie Institution has persisted and flourished through world wars, global pandemic, and economic cataclysm. Through it all, we have continued to ask bold questions and seek potentially transformational answers.

As you read this report, I want you to know that Carnegie scientists are rising to this exceptional challenge and making important contributions to the worldwide response to COVID-19. But even as we join forces with our colleagues in this battle against an elusive virus, we continue to pursue world-leading science that ranges from the depths of the Earth, to the mysteries of life, to the farthest reaches of the stars.

Thank you so much for your support of Carnegie and your commitment to our work and our community.

Sincerely,

Eric D. Isaacs

Eric D. Isaacs
President, Carnegie Institution for Science

2018-2019 YEAR BOOK

# The President's Report

July 1, 2018 - June 30, 2019

CARNEGIE INSTITUTION FOR SCIENCE

## Former Presidents



## Former Trustees

*“. . . to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind . . .”*

The Carnegie Institution was incorporated with these words in 1902 by its founder, Andrew Carnegie. Since then, the institution has remained true to its mission. At six research departments across the country, the scientific staff and a constantly changing roster of students, postdoctoral fellows, and visiting investigators tackle fundamental questions on the frontiers of biology, earth sciences, and astronomy.

## Carnegie Institution for Science



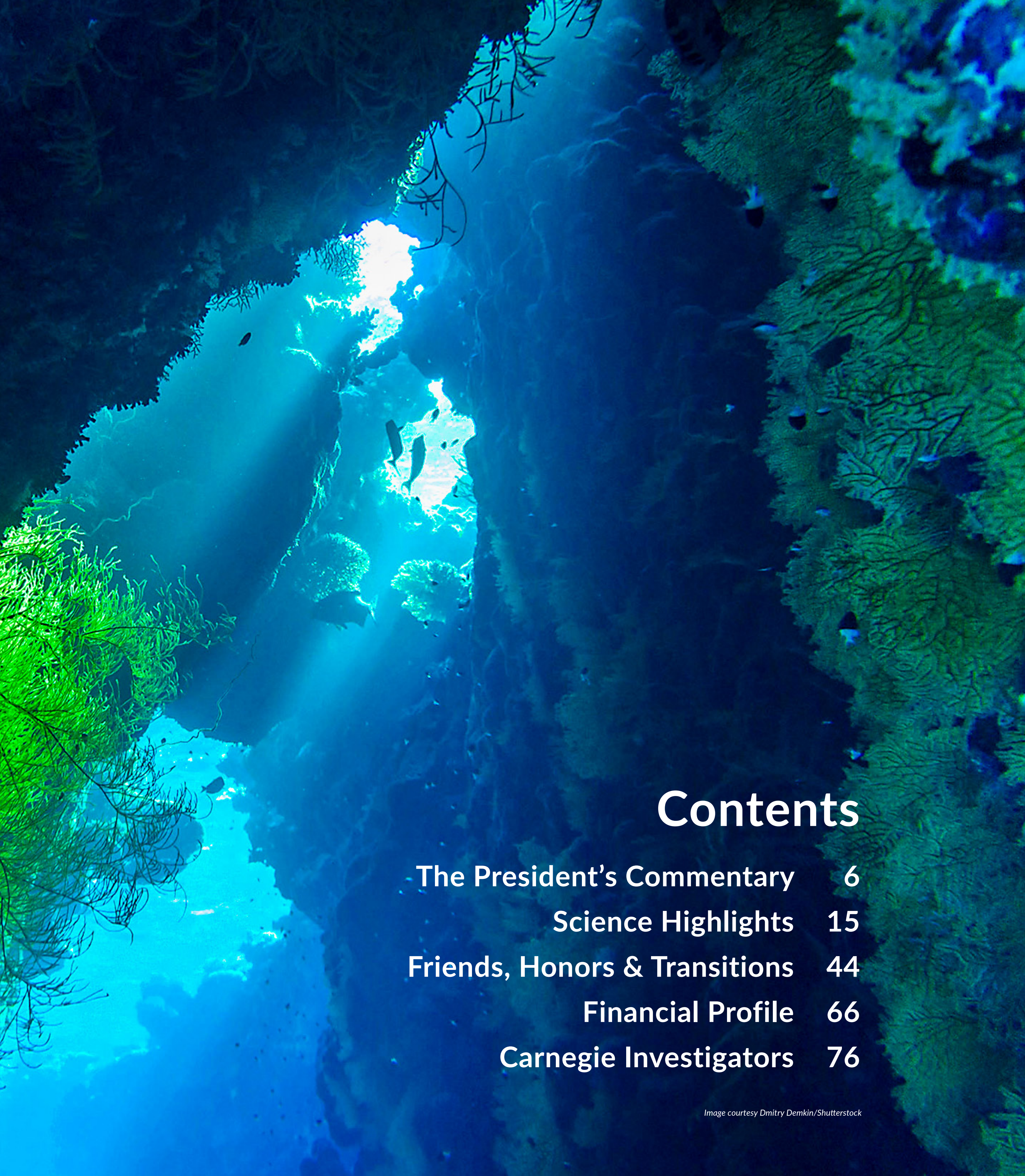

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*Image courtesy Dmitry Demkin/Shutterstock*

“**I look forward to the future** of Carnegie Science with even more enthusiasm, as we embark together on an **ambitious, thoughtful, and deliberate plan…**”

# The President's Commentary

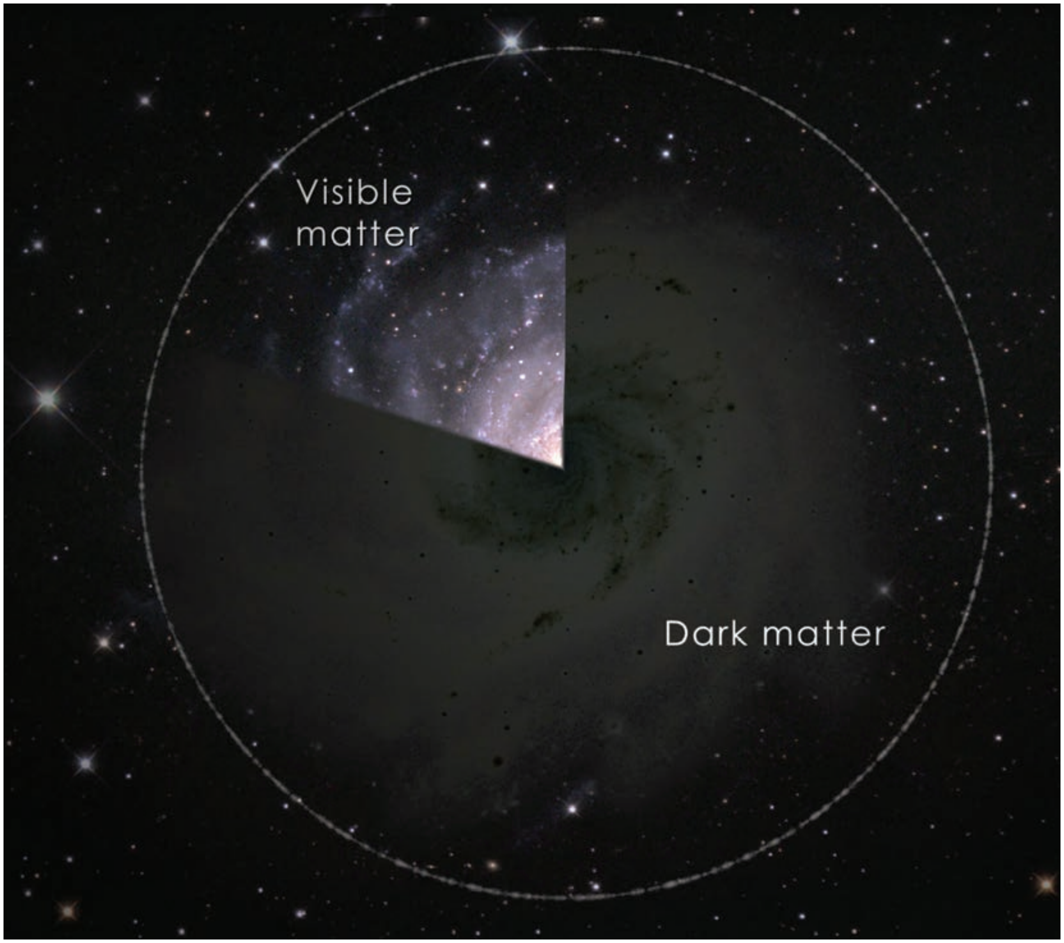
For more than a century, Carnegie scientists have taken pride in seeing farther and more clearly than anyone has ever done before. Today, as I look back at the work of our researchers featured in this Carnegie Science *Year Book*, I am inspired once again by the breadth and importance of their results, which range from explorations of microscopic proteins to measurements of literally cosmic proportion.

Carnegie president Eric D. Isaacs

*Image courtesy Jason Smith, University of Chicago*

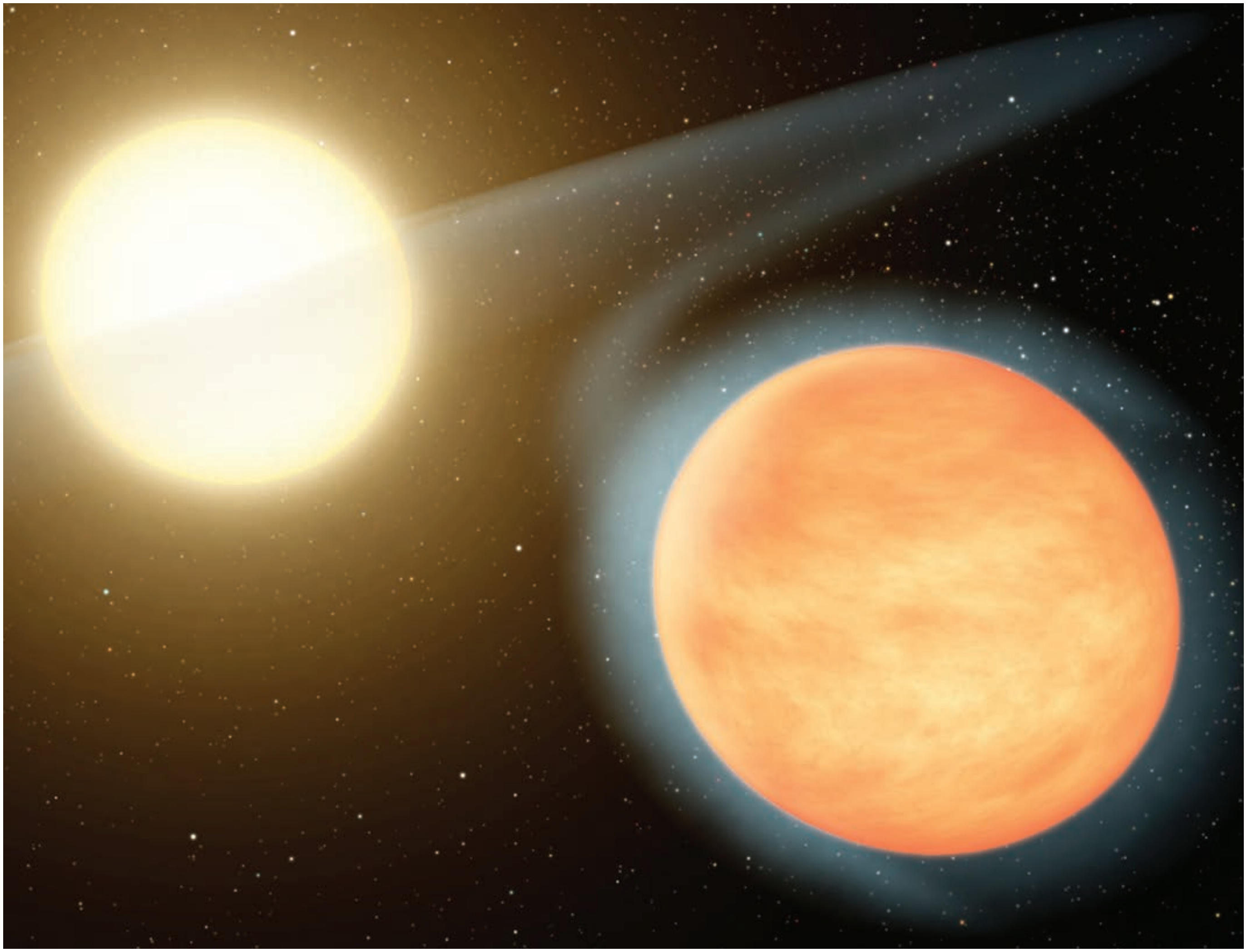
## Measuring Dark Matter

Researchers at the Observatories are continuing Carnegie's decades of interrogation into the enigma of dark matter—the invisible form of matter that makes up most of the universe's mass and influences its underlying structure. Staff scientist Andrew Benson, postdoctoral fellow Xiaolong Du, and student Turner Johnson are using a phenomenon known as "gravitational lensing" to detect and measure dark matter across cosmological distances. Gravitational lensing occurs when the gravity of objects such as massive galaxy clusters, which contain huge amounts of dark matter, bends and distorts the light of more-distant galaxies located behind the cluster. The Carnegie group looked at special cases of gravitational lensing, in which the distortion of a distant galaxy's light by a closer galaxy produces four images. By measuring the brightness of the images, the astronomers were able to develop models to identify likely concentrations of dark matter, down to a scale of $10^7$ times the mass of our Sun (amazingly precise, by cosmic standards).




Invisible material called dark matter constitutes some 85% of the mass of the universe. In the 1960s and 1970s, Carnegie's Vera Rubin, with Kent Ford, confirmed that dark matter exists. But dark matter continues to remain a mystery and is one of the most important astronomical inquiries today.

*Image courtesy NASA/GSFC*



This artist's rendition shows a very hot gas exoplanet with more carbon than oxygen (orange sphere), the first carbon-rich planet discovered. Dubbed WASP-12b, it was found by NASA's Spitzer Telescope some 1,200 light years away in the Auriga constellation. Sally June Tracy and Peter Driscoll are studying the interiors of carbon-rich "super-Earths" to understand the structure and evolution of these objects.

*Image courtesy NASA/JPL-Caltech/R. Hurt (SSC)*

## Probing Exoplanets

Carnegie researchers continued to do forefront work in the study of exoplanets, conducting lab-based, high-pressure and high-temperature experiments that will provide insights into the structure and evolution of these far-off worlds. Working with colleagues at Princeton University and Lawrence Livermore National Laboratory, Geophysical Laboratory staff scientist Sally June Tracy and Terrestrial Magnetism's Peter Driscoll used a laser-driven process to mimic the conditions inside the planetary mantles of carbon-rich super-Earths. Their study of the structure of silicon carbide under these extreme conditions provides new data that will be used to develop more accurate models of these exoplanetary interiors.

## Predicting Volcanic Eruptions

Here on Earth, National Science Foundation postdoctoral fellow Kathleen McKee joined staff scientists Diana Roman, Hélène Le Mével, and other collaborators to establish the first-ever quantitative link between the subsurface gas movements that occur before eruptions and the ensuing explosion. Their research on Stromboli Volcano combined the use of infrasound sensors with one of the first deployments of Carnegie's Quick Deploy Boxes (QDBs), compact and cost-effective broadband seismometers developed by the Department of Terrestrial Magnetism. Through their measurements of Stromboli Volcano's shallow "plumbing system," the researchers were able to quantify the flow rate of simple explosions—an important step toward their goal of reducing threats to communities near active volcanoes.

Carnegie researchers work in the field and lab to understand many aspects about the Earth. A Carnegie team, with colleagues, conducted experiments with a variety of instruments at Stromboli Volcano, Italy, (shown) to investigate how seismic signals from subsurface gas movement and acoustic signals from explosions are linked. Postdoctoral fellow Kathleen McKee is setting up a Forward Looking Infrared camera.

*Image courtesy Diane Roman, Carnegie Institution for Science*

## Tracing Lipoproteins

Working with molecular biologist Steven Farber in Carnegie's Department of Embryology, Johns Hopkins University graduate student James Thierer, now a postdoc in Farber's lab, developed an important new approach to studying Apolipoprotein-B (ApoB), the protein that shuttles fats and cholesterol through the circulatory system. Because ApoB is one of the largest protein complexes, it is difficult to study using traditional techniques. So, Thierer, in collaboration with the Mayo Clinic's Stephen Ekker, used cutting-edge genome engineering to tag ApoB in zebrafish with a glowing enzyme, similar to the one that lights up fireflies. The enzyme allows the researchers to monitor the movement of ApoB lipid complexes in larval zebrafish, which are entirely transparent. This highly sensitive approach has led to the discovery of a gene, called *PLA2G12B*, which seems to play a central role in packing lipids into lipoproteins before they are secreted into the bloodstream. The team is hopeful that this discovery will ultimately lead to effective new pharmaceutical treatments of high cholesterol and heart disease.


James Thierer (middle) was a graduate student in Steve Farber's lab when he conducted the work. After he successfully defended his thesis, "Illuminating cholesterol transport with larval zebrafish," he became a postdoc in the lab. Steve Farber (left), James Thierer, and department director Yixian Zheng (right) attend the celebration for Thierer's recently earned Ph.D.

*Image courtesy Navid Marvi, Carnegie Institution for Science*

## Understanding Plant Cell Growth

Although it is well known that environmental signals, including light, determine the growth and shape of plant cells, the exact mechanisms for these cells' response and reorganization has remained mysterious. To better understand the process, Carnegie's David Ehrhardt and team looked at the function of the protein katanin—named for the Japanese sword, katana—which responds to light perception by severing the intersections of microtubules within plant cells and triggering new growth. To understand how this process is stabilized in a growing plant, Ehrhardt and his team in Plant Biology studied the model plant *Arabidopsis thaliana* to understand the stabilizers at the point where severing occurs. After selectively deactivating candidate proteins by mutation and using time-lapse imaging to compare the mutants to normal plants, they found that the cytoplasmic linker associated protein (CLASP) works as a potent and specific stabilizer to promote regrowth after severing. These studies have important implications for understanding cellular function in both plants and animals.

*Arabidopsis thaliana* is a member of the mustard family. Its fast life cycle of six weeks, ease of cultivation in small spaces, and large seed production make it ideal to use as a model organism to study genetics, cellular development, and more.

*Image courtesy Robin Kempster, Carnegie Institution for Science*

## Analyzing "Wind Shadows"

With climate change accelerating, it is critically important to develop a comprehensive understanding of low-carbon sustainable energy, including wind power. To that end, Ken Caldeira and the Carnegie Energy Innovation Project in Global Ecology have undertaken an in-depth analysis of the geophysics of wind power. The project's models found that wind farms—large collections of wind turbines—create a "wind shadow" of disturbed airflow that can be detected more than 100 miles away. To better understand this phenomenon (which also can be caused by hills, buildings, and trees), postdoctoral fellow Enrico Antonini is studying the physics of atmospheric energy transport from the middle of the atmosphere to the wind turbines on Earth's surface. He has found that the number of turbine rows in a wind farm has a significant effect on the distance and velocity of the wind shadow. His research also looks closely at the ways power extraction changes with wind farm size, in hopes of supporting more productive siting decisions for future turbines.

To better understand the best placement for wind farms, the Carnegie Energy Innovation Project is studying the energy transport dynamics between the atmosphere and wind turbines, among other projects.
*Image courtesy iStockphoto.com/Ron and Patty Thomas*

## Setting A Course For The Future

After reviewing the highlights of this past year's endeavors, I look forward to the future of Carnegie Science with even more enthusiasm, as we embark together on an ambitious, thoughtful, and deliberate plan to strengthen our structure, extend our influence, increase our expertise, and assure our institutional health and independence in the years to come.

One of our first actions has been to unify our six scientific departments into three research divisions, focused on Earth and other planets, astronomy and astrophysics, and the life and environmental sciences. This action reflects input from a wide range of advisors, both inside and outside Carnegie. By bringing these divisions together, we are responding to the changing nature of science, which increasingly requires the combined efforts of diverse teams working across disciplinary boundaries. At the same time, we are instituting new programs to support individual researchers and labs, to ensure that the Carnegie tradition of intellectual freedom continues unabated. We also are investing in a new, diverse generation of brilliant researchers, whose boldness, individuality, and insatiable curiosity will ensure our continuing ability to ask—and to answer—some of the most significant scientific questions of our age.

As we move forward, we are exploring the possibility of developing new, long-term partnerships with world-class academic institutions that would help to support and expand our research opportunities and provide access to a wider range of scientific facilities. We are focusing on potential joint ventures that could include modernized facilities, combined fundraising and recruiting efforts, and shared commitment to growth in programs and staffing. Our goal in these partnership conversations is to strengthen our ability to conduct world-leading science while assuring Carnegie's independence in both scientific direction and internal governance.

From our founding, Carnegie scientists have been inspired by an ambitious mission: To expand our understanding of our world and our universe, and to apply our knowledge to the improvement of humankind. As we look to the future, we will be guided by that powerful mission as we continue building a foundation for new decades of scientific exploration and excellence.

Eric D. Isaacs

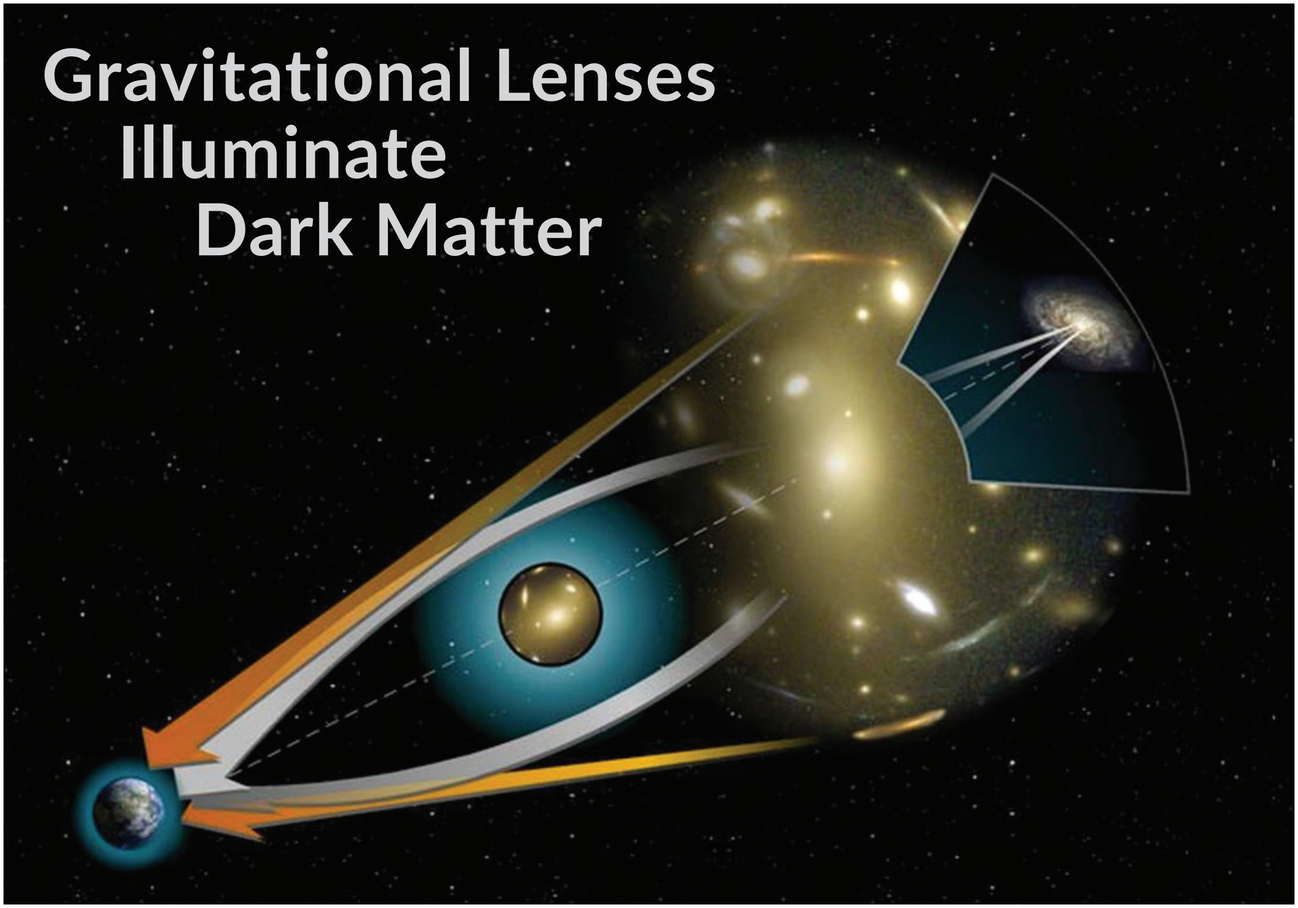
President, Carnegie Science

## 2018-2019 YEAR BOOK

# Science Highlights

*Image courtesy Hélène Le Mével, Carnegie Institution for Science*

# Gravitational Lenses Illuminate Dark Matter



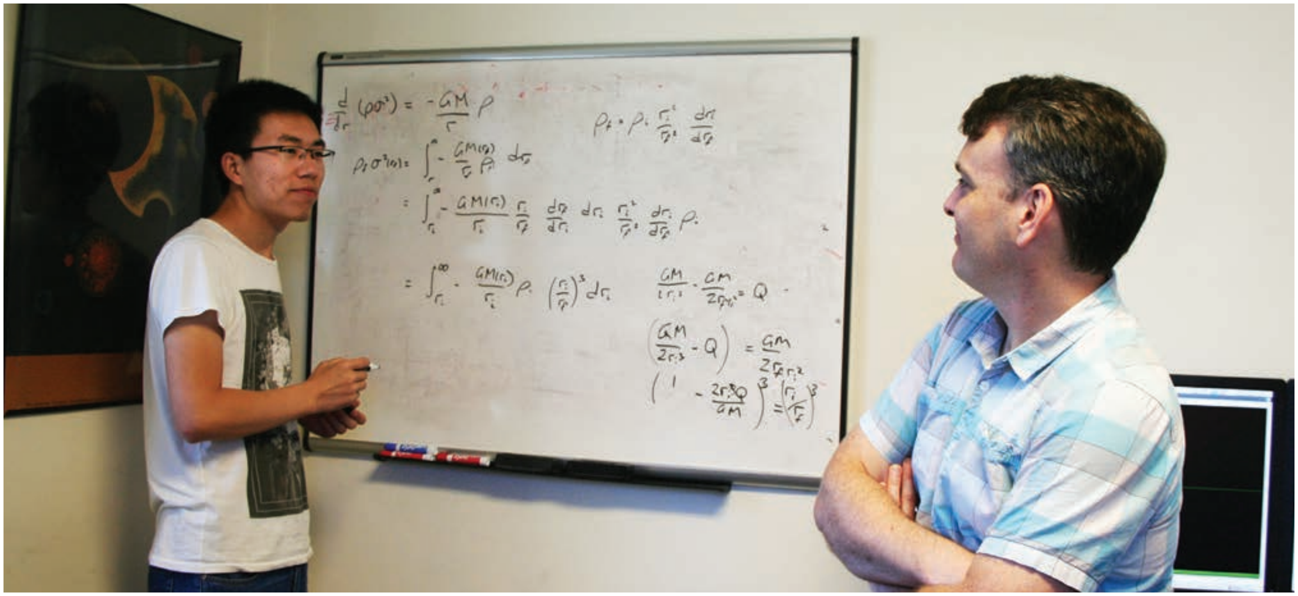
**Light from a distant object, such as the galaxy at far right, is gravitationally bent by a massive object or objects closer to Earth. The bending distorts the distant object, potentially creating multiple images of it.**

*Image courtesy NASA*

Invisible material called dark matter constitutes some 85% of the mass of the universe. In the 1960s and 1970s, Carnegie's Vera Rubin, with Kent Ford, confirmed that dark matter exists. Today we still do not know what dark matter is. Some models are good at explaining it at large scales, but not at small scales. Carnegie's Andrew Benson, with postdoctoral fellow Xiaolong Du and student Turner Johnson, are combining dark matter observations with theoretical modeling to analyze down to a scale of $10^7$ times the mass of our Sun—small in astronomical terms.

The team used a phenomenon called gravitational lensing, in which matter like galaxy clusters between a distant light source and Earth bends the light. The amount of bending is predicted by Einstein's general theory of relativity. This lensing enables the researchers to measure the distribution of matter across cosmological distances.

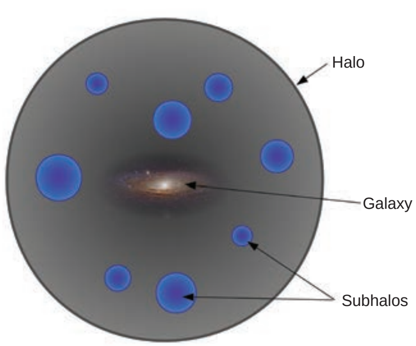
The astronomers looked at special cases of gravitational lensing—in which a distant galaxy's light is distorted by a closer galaxy, producing four images. This effect helps probe the mass function and density on subgalactic scales. Using general relativity, they could predict the relative brightnesses of the four images, which tells them about mass. In some cases, the measured brightnesses did not agree with predictions pointing to extra mass—small dark matter halos. Additionally, they can learn how many halos there are and where they are. The number and location depend on the properties of the dark matter particle—for instance, the lower the particles' mass, the fewer the small halos.

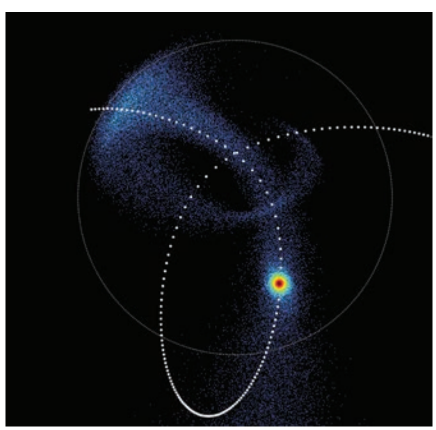


Postdoctoral fellow Xiaolong Du (left) and staff astronomer Andrew Benson (right) with student Turner Johnson, combined dark matter observations with theoretical modeling, using the phenomenon of gravitational lensing, to probe the mysteries of dark matter.
*Image courtesy Scott Rubel, Carnegie Institution for Science*

“. . . they could **successfully measure it** with their new system—a boon to understanding this enigmatic material.”

To isolate dark matter physics and to differentiate among particle types, the researchers needed to look at masses below $10^8$ solar masses. They applied forward modeling—which starts with causes to calculate effects—using changes in brightness ratios from the four images under different particle models. They then applied the calculation to 50 “mock” lenses, which included complicated physics such as the effects from gravitational drag, tidal forces, and other interactions. They ran the model tens of thousands of times to average results. They found that with 50 lenses it is possible to probe below $10^8$ solar masses and that if the mass of the dark matter particle is 200,000 times lighter than a hydrogen atom, they could successfully measure it with their new system—a boon to understanding this enigmatic material. ■



Using gravitational lensing, the researchers could measure the distribution of matter across cosmological distances. The measurements pointed to extra mass—small dark matter halos (left image). They could determine how many and where the halos are located. The image at right show a dark matter subhalo being pulled apart by the tidal forces of the larger dark matter halo in which it orbits. The blue shows dark matter that has been pulled away from the center of mass by the tidal forces. The colored points (blue, red, green, and yellow) show the subhalo where the dark matter is most dense, and the white shows the orbit that it followed.
*Images courtesy Xiaolong Du, Carnegie Institution for Science*

# Distance to the Large Magellanic Cloud Refined to One Percent

Both the Large and Small Magellanic Clouds can be seen at left in this view of the twin Magellan telescopes at Carnegie's Las Campanas Observatory in Chile.

*Image courtesy Yuri Beletsky, Carnegie Institution for Science*

Astronomers study the scale and expansion rate of the universe by observing nearby "standard candles," objects with a known luminosity, or brightness. These standard candles are then used to determine the distances to objects much farther away.

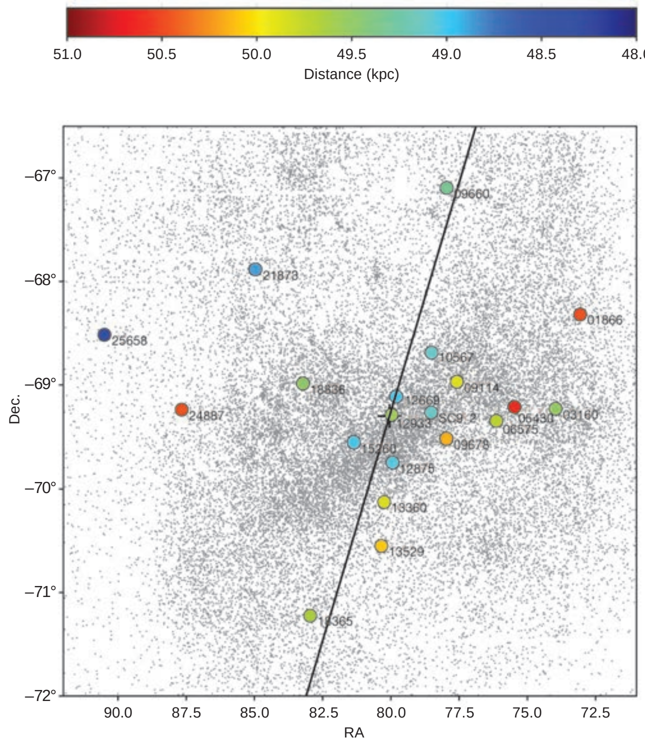
The Large Magellanic Cloud (LMC), a nearby galaxy, hosts a rich population of standard candles, particularly Cepheid variable stars. It is important to the calibration of extragalactic distances and in determining the expansion rate of the universe, called the Hubble Constant. The current uncertainty in the Hubble Constant is dominated by the uncertainty of the calibration of the relationship between the period and luminosity of Cepheids (the Leavitt Law). An accurate measurement of the distance to the LMC allows a more precise calibration of the Leavitt Law, which is used extensively in measuring distances to more distant galaxies. Ian Thompson and team have been studying 20 eclipsing binary stars in the LMC, and they have doubled the precision of measuring the distance to this galaxy—from 2% to 1%.

To determine their accurate distance to the LMC, Thompson and team measured an improved calibration of the relationship between the surface brightness and color of helium-burning giant stars. They then carefully selected 20 eclipsing binary stars in the LMC from a catalog of 35 million stars. Each component of the binaries is similar to their calibrating stars.

## “They believe their method of using binary stars for determining distances is robust. . . ”

Ian Thomspon, in the image above, works on instrumentation in addition to making astronomical observations.

*Image courtesy Scott Rubel, Carnegie Institution for Science*




The locations and distances of the 20 eclipsing binary stars studied in the Large Magellanic Cloud are shown in the diagram (above). Different colors indicate different distances to each system, per the bar at top.

*Image reprinted with permission Pietrzynski, G., et al., A distance to the Large Magellanic Cloud that is precise to one per cent, Nature, Vol. 567, 200-203 (2019) doi.org/10.1038/s41586-019-0999-4*

The astronomers then measured the changes in brightnesses as the binary stars eclipse, their orbital speeds, and the colors of the stars. With these data they determined the masses, stellar radii, and intrinsic brightnesses (from the surface brightness—color calibration) of the individual stars in the binary systems. The distance to each binary, and therefore to the LMC, comes from comparing the stars’ apparent brightness with their intrinsic brightness. After a detailed accounting for statistical and systematic errors by extensive modeling, the final measured distance to the LMC is 49.6 +/- 0.5 kiloparsecs, or 162,000 light years.

The team believes that their method of using binary stars for determining distances is robust for calibrating cosmological distances. They expect the accuracy of their method will be verified by comparison with other methods and data from the Gaia mission, which is making the largest and most detailed map of our galaxy and its environment. ■

# Journey to the Center of Super-Earths

Peter Driscoll and Sally June Tracy have joined forces to understand the interiors of carbon-rich exoplanets. Data from Tracy's high-pressure work mimicking conditions of super-Earth interiors will be used by Driscoll to develop mathematical models that can determine exoplanet structure and evolution. They were recently awarded a Carnegie Venture Grant for this project. These grants ignore conventional boundaries and bring together cross-disciplinary researchers with fresh eyes to explore different questions. In part, trustee Michael Wilson and his wife Jane and the Ambrose Monell Foundation generously support these grants.

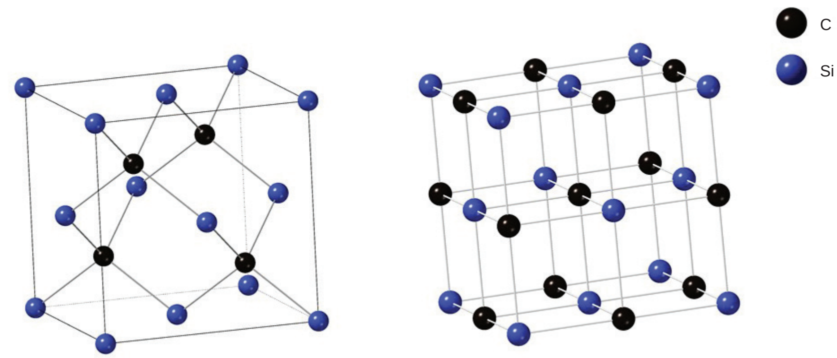
*Image courtesy Carnegie Institution for Science*

Carnegie's newest high-pressure scientist, Sally June Tracy, working with colleagues at Princeton and Lawrence Livermore National Laboratory, recently provided the first direct information on the structure of silicon carbide (SiC) using a rapid, pulsed-pressure technique called dynamic compression. SiC is important for making high-strength ceramics and is a likely component of exoplanet interiors. Tracy and Peter Driscoll are now using that success to conduct other high-pressure and temperature experiments mimicking conditions of carbon-rich super-Earth interiors with the goal of developing models of exoplanet structure and evolution.

At high-pressures and temperatures, the atoms making up materials are squeezed together to produce new structures. To generate extreme conditions in the laboratory, Tracy uses high-powered lasers to launch shock waves into samples. This method can achieve pressure-temperature states far greater than with static techniques, in which samples are squeezed between diamonds or tungsten carbide anvils. Laser-driven experiments generally have a duration of only a few billionths of a second. To accommodate these ultrafast timescales, Tracy uses the X-ray free-electron laser at the SLAC National Accelerator Laboratory, which allows observations of time-dependent atomic arrangements during shock and release.

Under ambient conditions, SiC atoms are arranged in a diamond-like crystal structure. Tracy's study found that under high pressures, above 2 million atmospheres (200 GPa), SiC crystallizes in a dense rock-salt structure. They also found a time lag with this rock-salt phase remaining intact for more than five nanoseconds as pressure was reduced to near ambient conditions. The sample eventually reverted to the low-pressure form.

# "Tracy's SiC high-pressure data can be used to develop these equations."




**Low-pressure 3C phase** **High-pressure rock-salt phase**

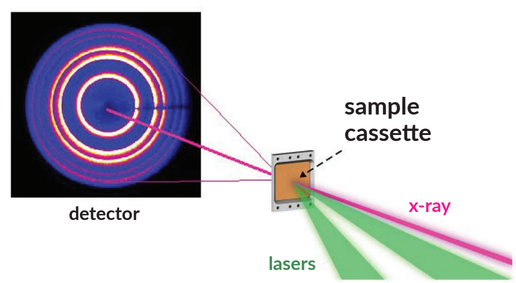
Under ambient conditions, silicon and carbon atoms are arranged in a diamond-like crystal structure (left image). Above 1 million atmospheres (100 GPa), silicon carbide (SiC) is transformed to a rock-salt structure, in which the atoms are squeezed much closer together (right).

*Image courtesy Sally June Tracy, Carnegie Institution for Science*

Interior mantles of carbon-rich super-Earths, exoplanets up to about 10 Earth-masses, are expected to contain different forms of SiC. However, models disagree about how the material behaves under extreme pressures. At about 1 million atmospheres (100 GPa), when SiC begins to transform to the rock-salt structure there is a ~20% density jump, which would affect interior structure, dynamics, and heat-loss rate. But reliable equations on the relationship of pressure, temperature, and volume at those high pressures are lacking so accurate modeling has been hampered.

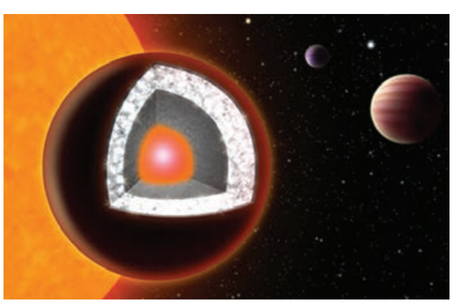
Tracy's SiC high-pressure data can be used to develop these equations. Driscoll will then be able to develop mathematical models of super-Earths' internal structures to understand how they develop and evolve. Tracy and Driscoll will also explore other carbon-bearing materials and apply this data to other models to constrain the structure and evolution of planetary interiors. ■

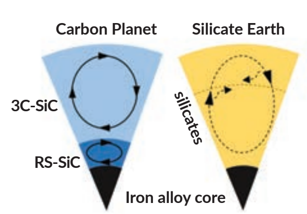
## Laser compression + pump-probe X-ray diffraction




This diagram shows how the rapid, pulsed-pressure technique called dynamic compression works. Samples are mounted on a translatable cassette. High-powered lasers launch a shock wave into the sample while high-intensity X-rays take a series of "snap shots" read by a detector as the shock alters the material's atomic configuration.

*Image courtesy Gregory Stewart, SLAC*






The artwork at left shows an exoplanet with a graphite surface surrounding an internal diamond layer, then a silicon carbide (SiC) layer around an iron core. The diagrams at right show how SiC from the ambient cubic carbon (3C) phase changes to the high-pressure rock-salt form in a carbon exoplanet. The diagram on the right shows silicates in the deep Earth. Details of how transformations occur as a function of temperature-pressure are believed to have profound influence on the interior structure and dynamics of a carbon world.

*Left image courtesy Haven Giguere, used with the permission of Yale University; right image courtesy Sally June Tracy, Carnegie Institution for Science*

# Improving Volcano Monitoring and Eruption Forecasting

"The goal is to reduce threats to communities near active volcanoes..."

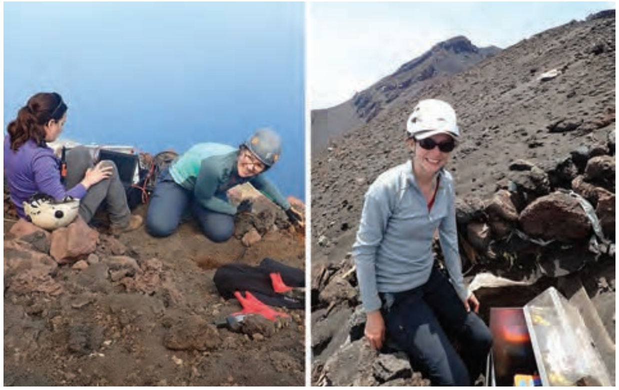
National Science Foundation postdoctoral fellow Kathleen McKee, along with staff scientists Diana Roman, Hélène Le Mével, and collaborators, is for the first time establishing a quantitative link between precursory activity and volcanic explosions. Specifically, the team is investigating how precursory seismic signals from gas movement in the subsurface and acoustic signals from explosions are linked by conducting an experiment at Stromboli Volcano in Italy. The goal is to reduce threats to communities near active volcanoes by developing an understanding of how observations such as tilt signals could be linked to explosion size.

Prior to erupting, volcanoes often inflate. That is, as magma and gas rise to the shallow subsurface from depth, they expand due to the decrease in pressure, in turn pushing on the surrounding rock and deforming the volcanic edifice. This deformation can happen over decades or quickly, over hundreds of seconds. Volcanic inflation is measured using satellites, GPS, tiltmeters, and seismometers to quantify volume change. The scientists deployed a variety of ground instruments including the recently developed Carnegie Quick Deploy Box seismometers, infrasound sensors, a MultiGAS instrument, gravimeter, and more to quantify the changes induced by volcanic activity.

The Carnegie team, with colleagues, conducted experiments at Stromboli Volcano, Italy, in May 2018. Five active vents that intermittently produce degassing plumes are shown at its summit (above).

*Images courtesy Hélène Le Mével, Carnegie Institution for Science*

McKee's expertise is in volcano seismology and infrasound—low frequency sound produced by eruptive activity, such as explosions or gas jetting, accelerating the atmosphere. Her goal is to connect geophysical measurements of subsurface to subaerial gas volume changes through the volcanic system. Shallow subsurface changes are measured with seismometers and tiltmeters and recorded as very-long-period seismic and tilt signals. Subaerial changes, explosions, are measured with specialized microphones sensitive to infrasound. The team wanted to link McKee's volcanic infrasound



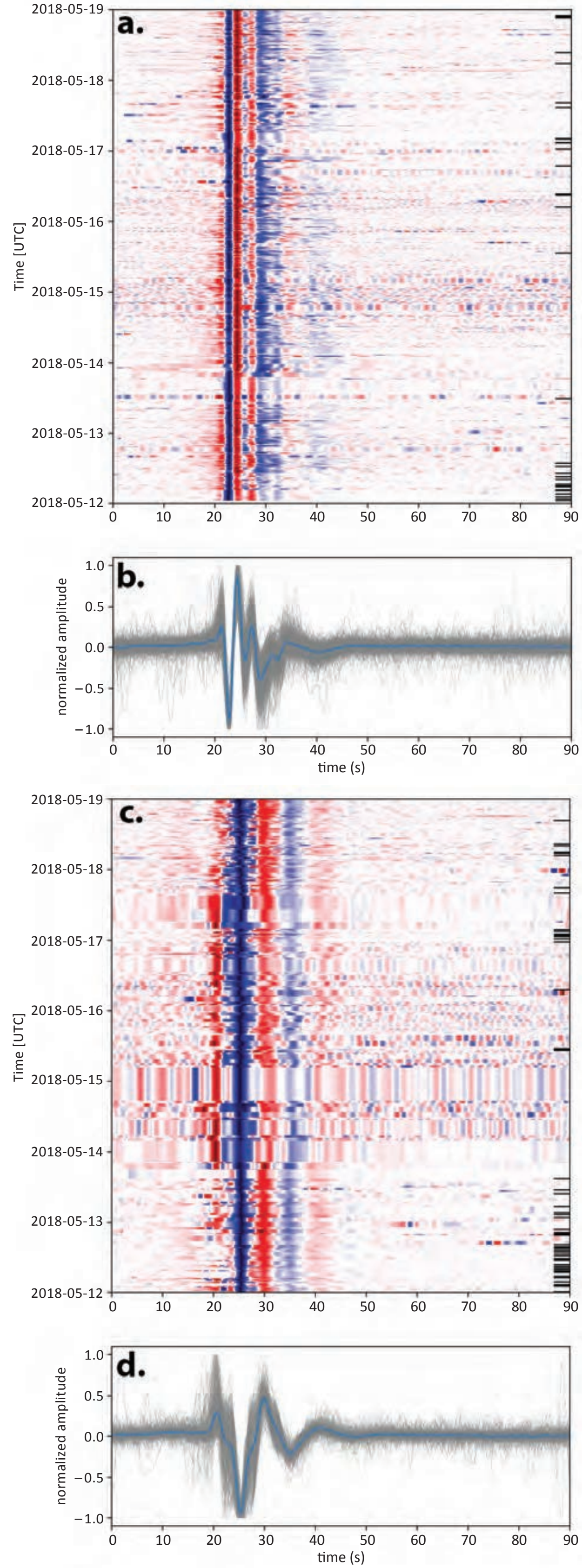
Carnegie volcanologists Diana Roman (left in left image) and Kathleen McKee are installing one of the Carnegie Quick Deploy Boxes developed with the support of The Brinson Foundation. Hélène Le Mével (right image) is taking measurements from a gravimeter used at Stromboli.

*Images courtesy Hélène Le Mével, Carnegie Institution for Science*

measurements of material erupted (i.e., gas and ash) to inflation signals from shallow accumulation of gas.

However, large deformation signals followed by large-scale eruptions produce highly complex acoustics. Volcanologists are currently working to quantify precursory deformation and erupted material in such large-scale eruptions. In contrast, the objective of the Stromboli work was to scale the experiments down such that the team could link small-scale signals with infrasound.

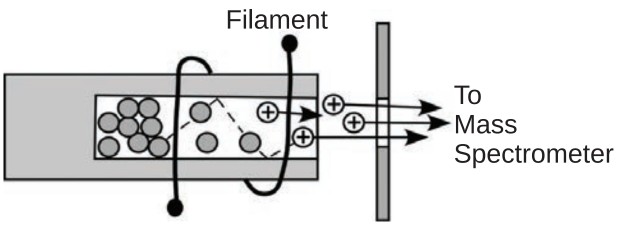
The researchers deployed gas instrumentation and compared those measurements to the gas volumes derived from infrasound and seismicity to determine the volumes of gas accumulated and emitted. Using volcano infrasound measurements, they were able to quantify the flow rate of simple explosions. The result is an important step for eventual forecasts of eruption size. ■




Very-long-period seismic signals (VLPs) usually indicate the movement of magma and or gas in the subsurface, often repeat over time, and produce highly similar waveforms indicating that the generating process is nondestructive. Kathleen McKee and Diana Roman found two families of repeating VLPs in the Stromboli seismic data from May 2018. Images a) and b) show the vertical component of Family 1, which repeats 500+ times over 7 days. Images c) and d) show the same for Family 2, which repeats about 200 times over the same period. The black horizontal bars in the right of a) and c) show when explosions occurred. Given there are less Family 2 VLPs and more bars indicating explosions in image c), Family 2 VLPs are more often correlated with explosions than Family 1 VLPs.

*Image courtesy Kathleen McKee, Carnegie Institution for Science*

# Developing Tools to Advance Earth Science




The drawing above shows a schematic of the cavity of the new mass spectrometer that is shown in the photo at top. Sample atoms (grey balls) are loaded into the cavity, which is then heated by electrons emitted from the filament (the glowing loop in the photo). The heating causes the cavity to glow and sample atoms to evaporate and bounce against the walls of the cavity until they become positively ionized, after which they are extracted into the mass spectrometer (to the right in the drawing and photo).

*Top image courtesy Rick Carlson, Carnegie Institution for Science; bottom image courtesy Jesse Reimink, Carnegie Institution for Science*

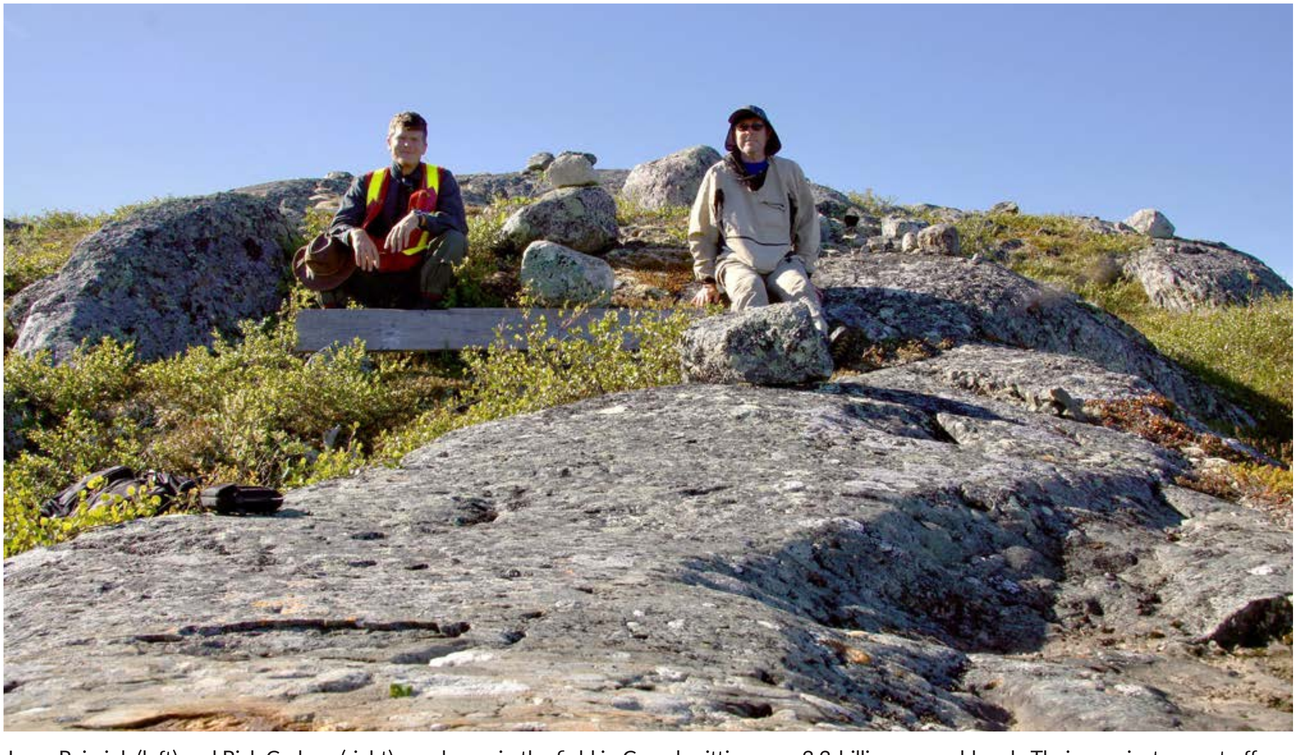
Carnegie researchers often design and build instruments to pursue new scientific questions. Few other organizations foster this capability. Geochemist Rick Carlson, with postdoctoral associate Jesse Reimink, is designing and building a new type of mass spectrometer. This Earth-science workhouse determines a sample's composition by creating ions, atoms with an electric charge, and then separating the ions by mass. The new design could increase sensitivity by 10-40 times, depending on the element, to allow the measurement of smaller samples or much higher isotope ratio precision on currently used sample sizes. Isotopes are versions of the same element that have different mass. The isotopic composition of an element can serve as a chronometer when it is changed by radioactive decay that occurs at a constant rate.

Mass spectrometry is the main technique used in radioactive dating of rocks and in tracing their origin to understand how and when planets formed and separated into core, mantle, and crust. The traditional mass spectrometer for this purpose uses a heated filament for sample evaporation and ionization. Carlson and Reimink's design replaces the filament with a tube, called a cavity. Sample atoms are loaded into the bottom of the cavity, which is then heated by high-energy electron bombardment, causing the sample atoms to bounce along the cavity walls until they become ionized. Once ionized, they are extracted by electric fields into the mass spectrometer.

Although the cavity ion source has been used in nuclear science since the 1970s, it has not yet been adapted to the geosciences. The scientists' goal is to design, build, and evaluate different configurations of cavity thermal ion sources that optimize various performance trade-offs and that can be easily fitted to existing mass spectrometer components. Results to date show that the new cavity ion source matches or exceeds expectations for ionization efficiency and transmission into the mass spectrometer for a number of elements with geochemical applications. The expected improvement in isotope ratio precisions will reduce the uncertainty in the timing of the events accompanying Earth formation 4.5 billion years ago from tens of millions of years to under a million years. This will greatly improve our ability to determine the sequence of events that formed and modified Earth. ■

> "Results to date show that the new cavity ion source matches or exceeds expectations..."





Jesse Reimink (left) and Rick Carlson (right) are shown in the field in Canada sitting on a 3.3-billion-year-old rock. Their new instrument offers the promise of using ancient rocks like these to better understand the processes that created the first crust on Earth.

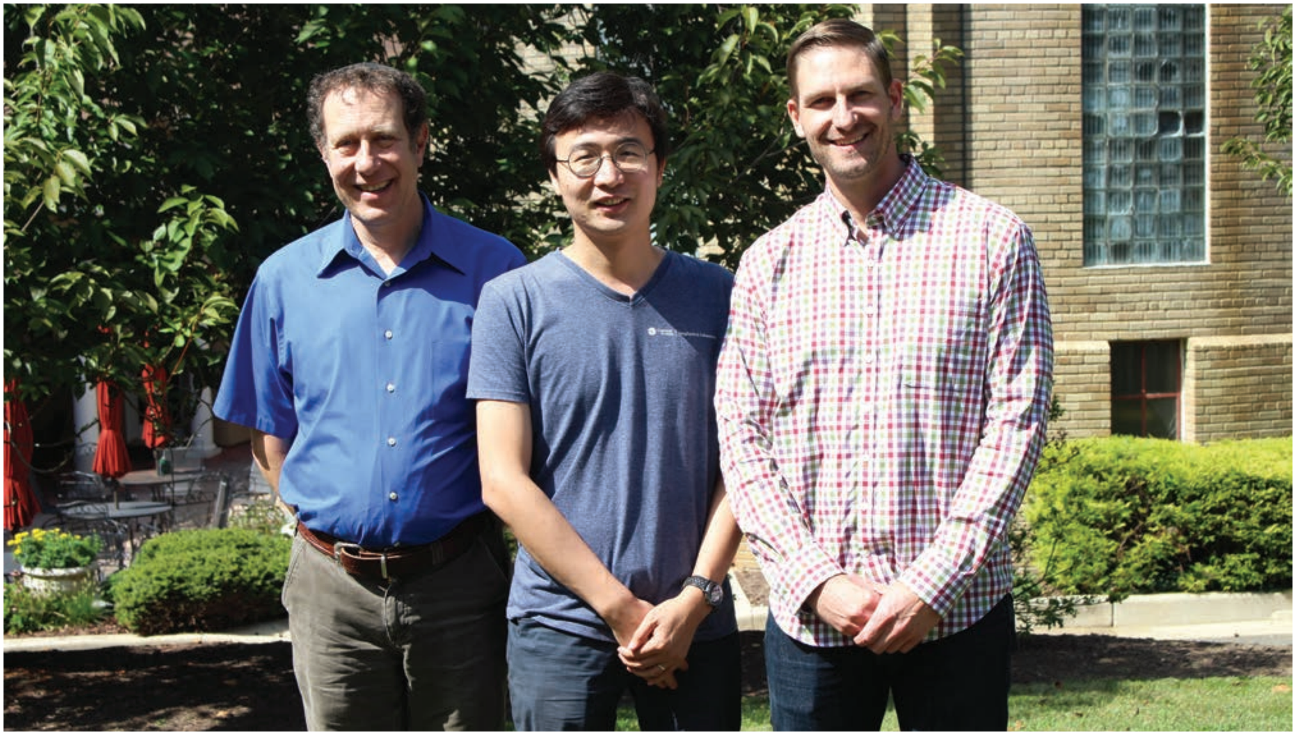
*Image courtesy Rick Carlson, Carnegie Institution for Science*

# New Method for Predicting How Materials Change

Li Zhu, Ronald Cohen, and Tim Strobel use experiments and modeling to reveal how materials behave under different pressure and temperature conditions. When atoms are squeezed together they behave very differently. Researchers need to understand how they change under pressure into new phases—like graphite into diamond—both are forms of carbon, but with different arrangements of atoms. Their objective is to fundamentally understand these changes, which can lead to the discovery of novel materials for different applications.

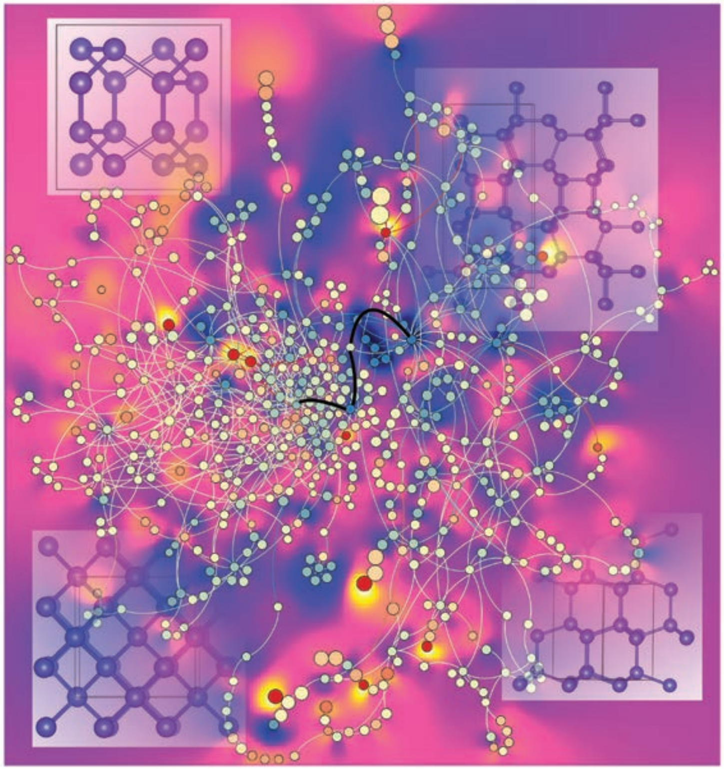
The team developed a new method called PALLAS, named after Pallas Athena, the goddess of wisdom, to automatically predict the atomic rearrangements involved as materials undergo transitions from one phase to another. They successfully tested the method against known transitions in cadmium selenide (CdSe), a semiconductor, and silicon (Si), the cornerstone of technology and an element that constitutes almost 30% of Earth's crust.

The spatial arrangement of atoms consists of many valleys and hills that represent energetically favorable and unfavorable states. Knowing these states and the potential pathways between them provides valuable information regarding stability and synthesis through a principle known as transition state theory. For one configuration of atoms to transform to another, the system must overcome an energetic barrier.



Ronald Cohen (left), Li Zhu (middle), and Tim Strobel (right) use experiments and modeling to reveal how materials behave under different pressure and temperature conditions.

*Image courtesy Carnegie Institution for Science*



> " . . . to **automatically predict the atomic rearrangements** involved as materials make these transitions."



PALLAS predicted this complex transition pathway network for silicon. It is a road map that shows possible transition pathways between different structures. PALLAS correctly identifies the lowest-energy transition pathway for silicon upon decompression from high pressure (thick black line). The structures in the four boxes show the different configurations of atoms along the transition path. The background colors indicate contours on the energy landscape. The points indicate stable and metastable structures of silicon with their size and color proportional to volume and energy, respectively. The composite of circles is similar to methods used in social networking analysis.

*Image courtesy Tim Strobel, Carnegie Institution for Science*

Although there are existing approaches to determining these pathways, there are major limitations analyzing transitions between complex crystal structures.

The team used swarm intelligence and graph theory in PALLAS. Swarm intelligence considers the collective intelligence of a system, such as the effective performance of a colony of ants over one ant alone, while graph theory studies the relationship among data points within complex networks. PALLAS predicts the stable and metastable crystalline structures and the transition pathways that connect them without preexisting information.

They compared results from PALLAS against known phase transitions in cadmium selenide and silicon. PALLAS identified previously known, low-energy phase transition pathways for the wurtzite to rock-salt structures in cadmium selenide and, importantly, revealed a new lower-energy pathway not yet observed.

For silicon, PALLAS explained the labyrinthine phase transition steps observed when it is decompressed from high pressure, revealing the complex sequence that deviates from the most stable structures. By understanding detailed phase transition mechanisms, PALLAS can be used to guide synthesis of future materials, including materials found in deep planetary interiors, including so-called super-Earths, and for new technology, and to possibly address biological problems such as protein folding. ■

# The Carnegie Energy Innovation Project

The Carnegie Energy Innovation Group includes (front row on ground, from left): Nienke Besbrugge, Emmie Le Roy, and Tyler Ruggles; (second row, from left): Manoela Romano de Orte, Elizabeth Susskind, Dan Tong, Candise Henry, Nate Lewis, Ken Caldeira, and Lei Duan; (back row, from left): David Farnham, David Koweek, Enrico Antonini, Yixuan Zheng, Steve Davis, and Rebecca Peer.

*Image courtesy Candise Henry, Carnegie Institution for Science*

Looking to produce a better future, in 2017 the Ken Caldeira lab embarked on the Carnegie Energy Innovation project to produce fundamental scientific knowledge to help inform societal decisions about our energy systems. The goal is to facilitate a transition to a sensible, near-zero emission energy system. The work includes evaluating the efficacy and potential unintended consequences of proposed solutions to climate and energy problems.

Humans have transformed our planet. The world used to be largely dominated by nature, but now humans dominate by transforming the land with agriculture and other development, the atmosphere with emissions, and the oceans with pollution and overfishing.

Global ecology is the relatively new science that studies how humans interact with the planet's natural systems. One of the key human interactions is through our energy system—we rely on nature for our energy, whether it's from coal, oil and gas, or wind and sunlight.

One example of the Carnegie Energy Innovation analysis concerns the geophysics of wind power. Individual wind turbines are well-known to produce a "wind shadow" in their wake. Recently, through the project's modeling, it was found that wind farms—large collections of wind turbines—also leave a wind shadow that can be detected more than 100 miles away. Enrico Antonini, a Carnegie postdoctoral fellow, is trying to understand the physics of atmospheric

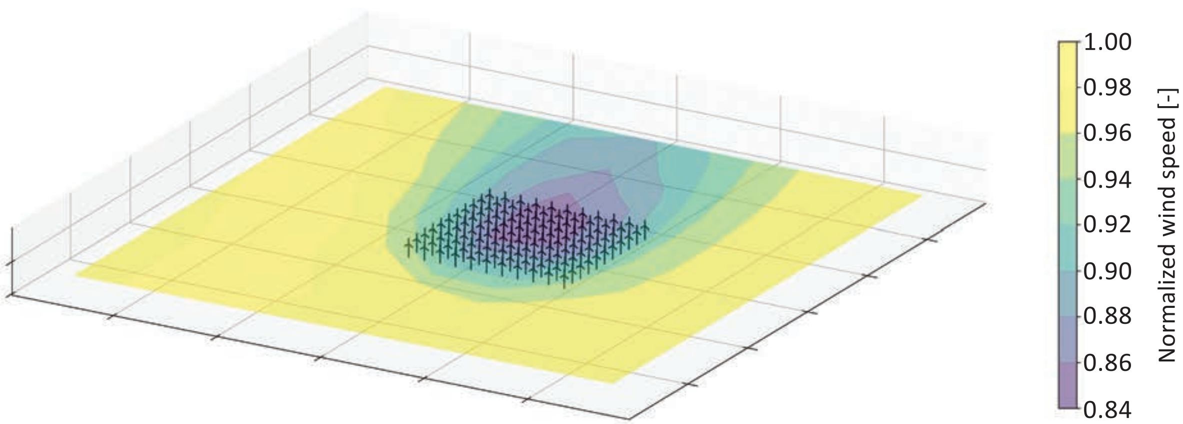
## “The goal is to facilitate a transition to a sensible, near-zero emission energy system.”

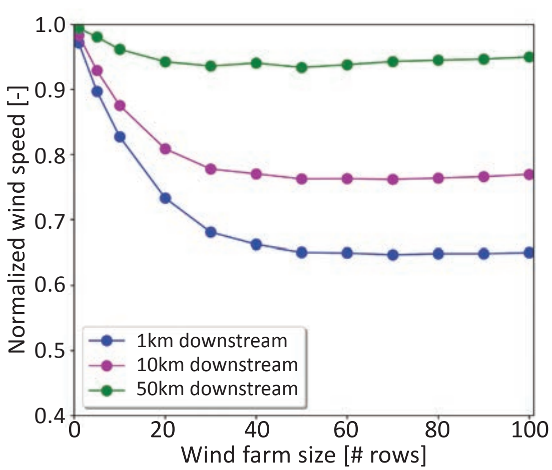
energy transport from the middle of the atmosphere to the wind turbines on Earth’s surface. This will help lead to better planning and siting decisions for future wind farms.

Geophysical scientists are trained to study complex global systems using first-principles simulations, which begin with fundamental laws and conservation equations, then numerically build on them to find solutions. This approach is different from the more common device-level energy engineering approach. Carnegie’s independence allows the researchers to focus on the fundamentals of century-scale energy system transitions and share results with complete openness and transparency so that others may make better decisions.

In addition to geophysical modeling, the Carnegie Energy Innovation group explores energy system modeling, to study the architectures of different zero-emission energy systems; economic modeling, to understand the economic impact of different solutions; and energy/climate related analysis that can show, for instance, how the same changes in different locations can have very different climate effects. All have the ultimate goal of achieving a zero-emission energy system through thoughtful and rigorous analyses. ■






Individual wind turbines produce a “wind shadow” in their wake. Recently, through Carnegie Energy Innovation project modeling, it was found that wind farms—large collections of wind turbines—also leave a wind shadow that can be detected more than 100 miles away. The darker purples in the image of a turbine farm above indicate the slower wind speeds. These turbine farms create a wind shadow. The graph at left shows how the winds slow down at different distances from farms with varying numbers of turbine rows.

*Images courtesy Enrico Antonini, Carnegie Institution for Science*

# The Science of Green Slime: Climate Change is Harming Water Quality

The team's study of algal blooms in over 70 lakes across the globe found that water quality in most lakes has deteriorated over the last 30 years. One example is Lake Okeechobee in Florida, where states of emergency were declared in 2016 and 2018 due to toxic algae.

*Image Courtesy NASA Earth Observatory image made by Joshua Stevens, using Landsat data from the U.S. Geological Survey*

Everyone needs clean water. Scientists understand much of the climate impacts on water quantity—from droughts to flooding—but little about how climate impacts water quality. Anna Michalak's lab is elevating the understanding of the relationship between climate and water quality for lakes, rivers, and coastal zones worldwide. Her focus has been on nutrient runoff and the harmful algal blooms with resulting low-oxygen dead zones.

Intense or heavy rainfall washes nutrients from land into rivers and lakes. With rising temperatures, this runoff promotes harmful algae growth and reduces water mixing in lakes and along coasts, allowing algae to proliferate, releasing toxins, depleting oxygen, creating dead zones, and disrupting municipal water supplies.

Recently, Michalak's lab showed that precipitation and temperature play a much stronger role in water quality than was previously understood. Using historical U.S. data, they derived robust, quantitative relationships between meteorology and nitrogen runoff, harmful algal blooms, and dead zones. They then examined how future climate change, as well as societal mitigation efforts, will impact water quality.

In 2017, the lab showed that anticipated rainfall changes over the U.S. will lead to a 20% increase in nitrogen runoff in the coming decades. It would take a one-third decrease in nitrogen fertilizer use to offset the climate impact or make water cleaner than it is today. Looking globally, the team found that parts of Asia, including India and China, are particularly susceptible to similar impacts. In 2019,

> “...precipitation and temperature play a
> **much stronger role in water quality**
> than was previously understood.”



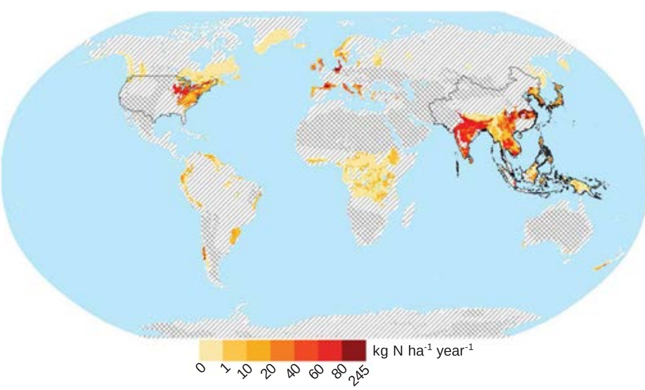


Left to right: Eva Sinha, Jeff Ho, Dario del Giudice, and Tristan Ballard have been involved in the water quality work in Anna Michalak's (far right) lab described in this highlight.

*Images courtesy Carnegie Institution for Science*

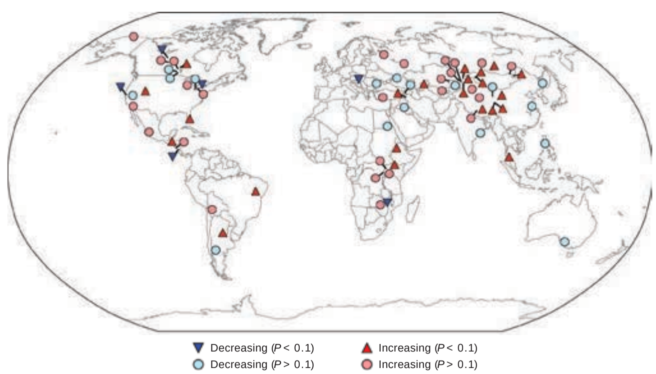
the team showed that climate mitigation efforts focusing on biofuels could surprisingly exacerbate nutrient pollution. However, they also found there are solutions to protect both water and the climate.

The team recently looked to past decades, questioning whether climate change has already impaired water quality. They examined nutrients entering U.S. waterways and found that trends since the 1980s correlate with changes in total precipitation, extreme precipitation, and temperature much more so than do changes in land use and land management. In another study using billions of historical data points from the Landsat satellite, they also showed that over two-thirds of lakes globally have experienced an increase in intense algal blooms since the 1980s. Only lakes that warmed the least showed some improvement, which means that water is already less clean from climate change. The team is now examining other facets of this problem, such as how much more likely extreme algal blooms have become as a result of climate change. ■




This image shows current fertilizer application rates for regions around the globe that receive heavy precipitation and that are highly likely to see further increases in precipitation as a result of climate change. Regions depicted in orange and red are at highest risk of water quality impacts resulting from climate change, since climate change will interact with local land management to increase nutrient runoff.

*Image reprinted with permission from AAAS, E. Sinha, A. M. Michalak, V. Balaji, Eutrophication will increase during the 21st century as a result of precipitation changes, Science 357, 405-408 (2017)*




This image shows how the intensity of algal blooms has changed for dozens of lakes globally since the mid-1980s. The intensity of blooms has increased for over two-thirds of the examined lakes (red symbols), and the increase is statistically significant (red triangles) for one-third of examined lakes.

*Image reprinted with permission Ho, J.C., Michalak, A.M. & Pahlevan, N. Widespread global increase in intense lake phytoplankton blooms since the 1980s, Nature 574, 667-670 (2019) doi:10.1038/s41586-019-1648-7*

# How New Plant Species Arise

"...untangles the mechanism that keeps maize—corn, a grass—distinct from some strains of its ancestor..."

The creation of a new species in evolution requires a reproductive barrier. Determining the genetic and molecular nature of reproductive barriers is an age-old inquiry. New research led by Carnegie's Matthew Evans, with Carnegie's Yongxian Lu, Samuel Hokin, and Thomas Hartwig, plus Jerry Kermicle of the University of Wisconsin, Madison, untangles the mechanism that keeps maize—corn, a grass—distinct from some strains of its ancestor teosinte.

Speciation requires isolation. Sometimes isolation is facilitated by geography that divides two populations, preventing them from interbreeding until they become different species. In other instances, separation is physiological, preventing successful mating or viable offspring.

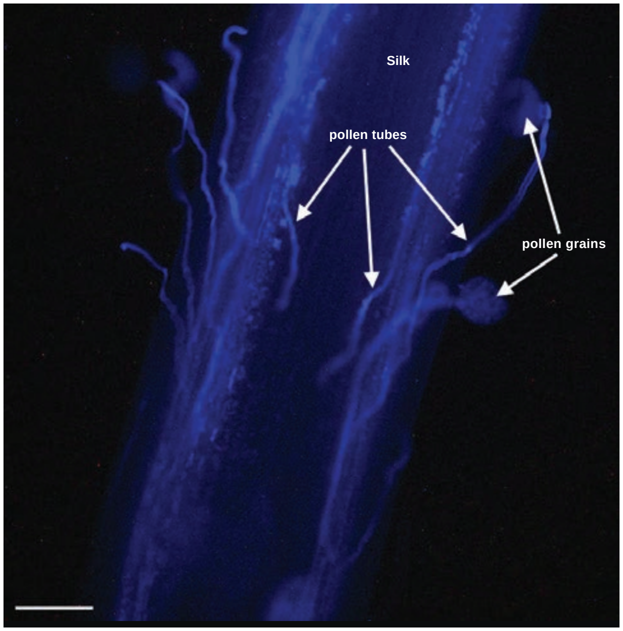
In plants, genetic isolation can be maintained by features that prevent the "male" pollen of one species from successfully fertilizing the "female" pistil of another species.

About 9,000 years ago, maize was domesticated from teosinte in the Balsas River Valley of Mexico. Some populations of the two grasses are compatible for breeding. But others grow in the same areas and flower at the same time but rarely produce hybrids.

It was known that a cluster of genes called *Tcb1*-s is one of three that confers incompatibility between rarely hybridizing maize and teosinte populations. But unlike the other two, it is found almost exclusively in

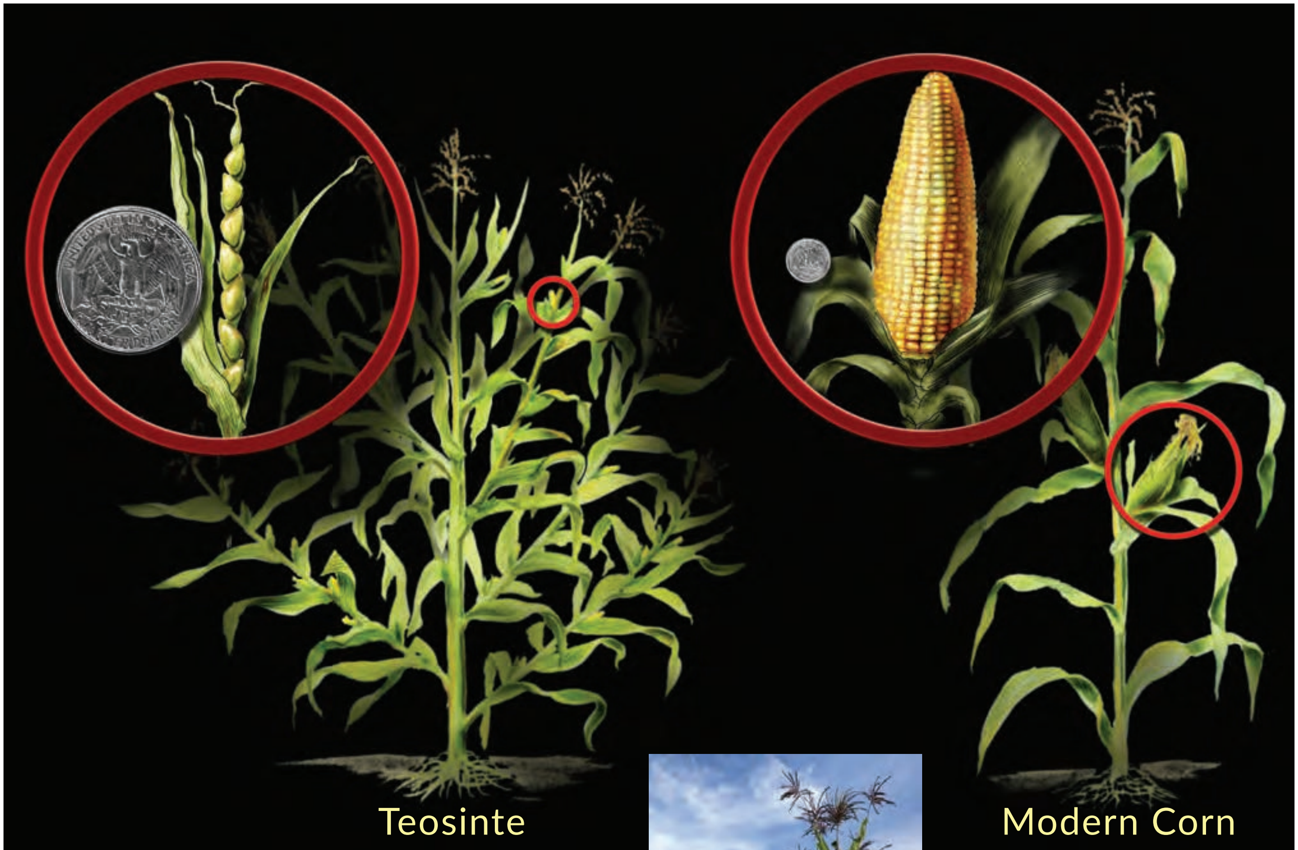
Matt Evans led the study of species distinction.

*Image courtesy Robin Kempster, Carnegie Institution for Science*




This image shows the pollen tubes of pollinated maize silk. The pollen tubes were stained using aniline blue (scale bar = 100µm).

*Image reproduced with permission of CAB International, from Maize Kernel Development*




About 9,000 years ago, maize (right) was domesticated from teosinte (left) in the Balsas River Valley of Mexico. The artwork compares the features of the two species. The photograph at right shows a teosinte plant on the Stanford University campus.

*Images courtesy Nicolle Rager Fuller, National Science Foundation and Yongxian Lu, Carnegie Institution for Science*

wild teosinte. It contains both female and male genes that program wild teosinte to reject maize pollen but fertilize itself, respectively.

In sexually compatible plants, the pollen—a sperm delivery vehicle—lands on the pistil and forms a tube that elongates and burrows into the ovary, where the egg is fertilized. This does not happen when maize pollen lands on the pistil, or silk, of these wild teosinte plants.

Evans and colleagues demonstrated that the *Tcb1*-female gene encodes a protein that is capable of modifying cell walls, likely making maize pollen tubes less elastic, preventing them from reaching the teosinte eggs. When these tubes can't stretch to the eggs, fertilization can't occur and hybrids won't arise.

Additionally, because teosinte pollen can fertilize itself, the researchers think that the *Tcb1*-male genes encode an ability that allows teosinte pollen to overcome this pollen tube barrier.

Knowing the *Tcb1*-female gene now allows tests on the cellular mechanisms of pollen rejection and determining if the *Tcb1*-female gene family plays a role in reproductive isolation and speciation more broadly in grasses. ■

# Deciphering How Plants Grow


The Ehrhardt lab members are, from left to right: Jelmer Lindeboom, Jacob Moe-Lange, Sury Jha, Mackenzie Machado, Renate Weizbauer, and David Ehrhardt. Heather Meyer is not pictured.
*Image courtesy David Ehrhardt, Carnegie Institution for Science*

Plant cell growth and shape is determined by the extension of their cell walls. To direct cell wall construction and growth, plant cells have a highly organized interior scaffolding called a microtubule cytoskeleton. Environmental signals, including light, reorganize this scaffold to make growth responsive to environmental changes. Carnegie's David Ehrhardt and team discovered that this reorganization is driven by creating new microtubules by an unexpected process where the protein katanin severs the microtubules where they intersect, creating new "plus" ends that regrow.

They then asked how, after katanin cutting, the plus ends stabilize to promote microtubule generation. The team identified the protein CLASP as a potent stabilizer of these new plus ends. This research provides new avenues for engineering how plants respond to environmental changes and advances our understanding of how similar cytoskeleton mechanisms may work in animal cells, including those in humans.

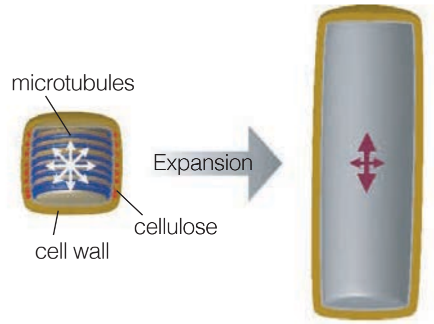
Microtubule plus ends switch from slowly growing to rapidly shrinking. The growing ends are stabilized by

binding the molecule GTP and by proteins associated with growing ends, creating a stabilizing "cap." When severing occurs in vitro behind the stabilizing cap, the new plus ends shrink. However, that is not what is observed in living cells—the new plus ends typically grow. Models indicate that end growth after severing is required to create a new population of microtubes. The required stabilizing factors, however, are unknown.

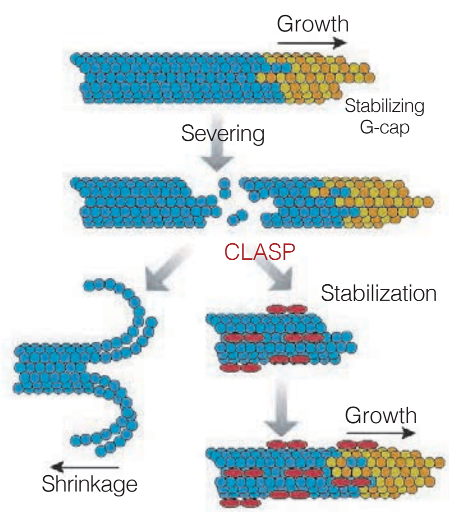
"…this reorganization is driven by creating new microtubules by an unexpected process…"

Ehrhardt and Carnegie colleagues Jelmer J. Lindeboom, Masayoshi Nakamura, and Ankit Walia used the model plant *Arabidopsis thaliana* to understand the stabilizers behind the GTP-cap, where severing occurs. They looked at candidate proteins that accumulate at the plus ends and asked whether one or more of them might support the creation of new microtubule arrays following light stimulation. They selectively deactivated candidate proteins by mutation and compared the mutants to normal plants using time-lapse imaging of the microtubule arrays. Combined with analysis by computational modeling, they revealed that the protein CLASP is a potent and specific stabilizer of plus ends created by severing in vivo and that this activity is required to build a new array after light stimulation.

The researchers are currently investigating the mechanisms by which CLASP stabilizes the cut ends and promotes regrowth. These studies have implications for understanding cellular function in animals, where CLASP is conserved, and where important cell types, including neurons, are proposed to create microtubules arrays by severing and regrowth. ■

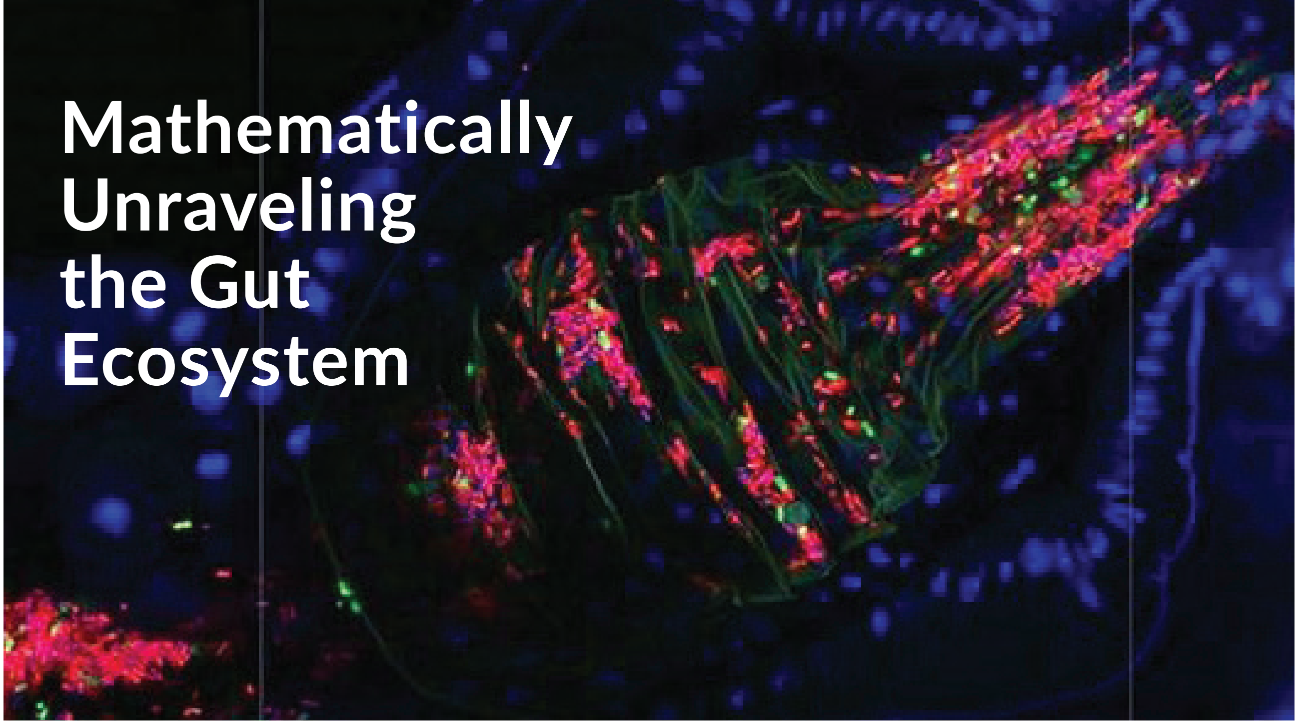



Plant cells are under high internal pressure (white arrows), which pushes against a rigid cell wall. An organized microtubule cytoskeleton (blue) directs cell wall synthesis (red) and loosening, determining how the wall yields to create the cell's shape.
*Image courtesy David Ehrhardt, Carnegie Institution for Science*




Plant cell growth is directed by shifting arrays of hollow cylinders of protein filaments called microtubules (top). Microtubules are assembled from pairs of tubulin proteins. When first assembled, interactions among neighboring tubulin pairs are strengthened by the binding of a small molecule called GTP. This stabilizing "G-cap" promotes continued filament growth. When plant cells in the plant axis perceive light, new microtubules are created by severing existing ones (second from top), reorienting the microtubule array and modifying cell growth. However, this severing occurs behind the G-cap. The protein CLASP steps in to stabilize the new ends (third from top) that severing creates preventing them from shrinking and promoting their growth to create the new array (bottom).
*Image courtesy David Ehrhardt, Carnegie Institution for Science*

# Mathematically Unraveling the Gut Ecosystem

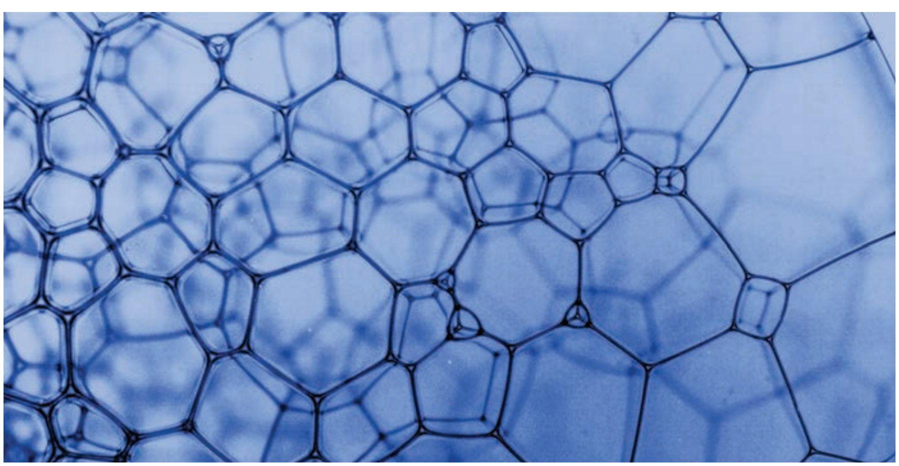


This super-resolution image shows fruit fly gut crypts colonized by the native *Lactobacillus* (red) and *Acetobacter* (green) bacteria. Fly cell nuclei appear blue.

*Image courtesy Benjamin Obadia and Will Ludington*

The interactions among microbial species in the gastrointestinal system can have large effects on health, development, and longevity. This ecosystem, called a microbiome, has hundreds to thousands of microbial species in the mammalian gut. The diversity within the human gut challenges our understanding of its effects on health. Will Ludington and team are using the simpler fruit fly gut as a model system to understand how complex microbial interactions affect our health. Their ultimate goal is to use this predictive power to engineer the microbiome.

The effects of a particular microbial species depend on the context of other species. Using the fruit fly *Drosophila melanogaster*, Ludington and team developed a mapping system of all the possible interactions between the five species of fly gut bacteria to see how they affect an insect's development, production of offspring, and lifespan. The team found that the interactions among microbial populations are as important to the fly's physiology as the individual species.



The microbiome consists of many interacting microbial species. Ludington's team is deconstructing this complexity by calculating the geometric structure of the interactions. Their method measures interactions in multidimensional space, considering each species to have its own dimension. The mathematical structure can be thought of as foam being simplified into a single bubble by progressively merging adjacent bubbles.

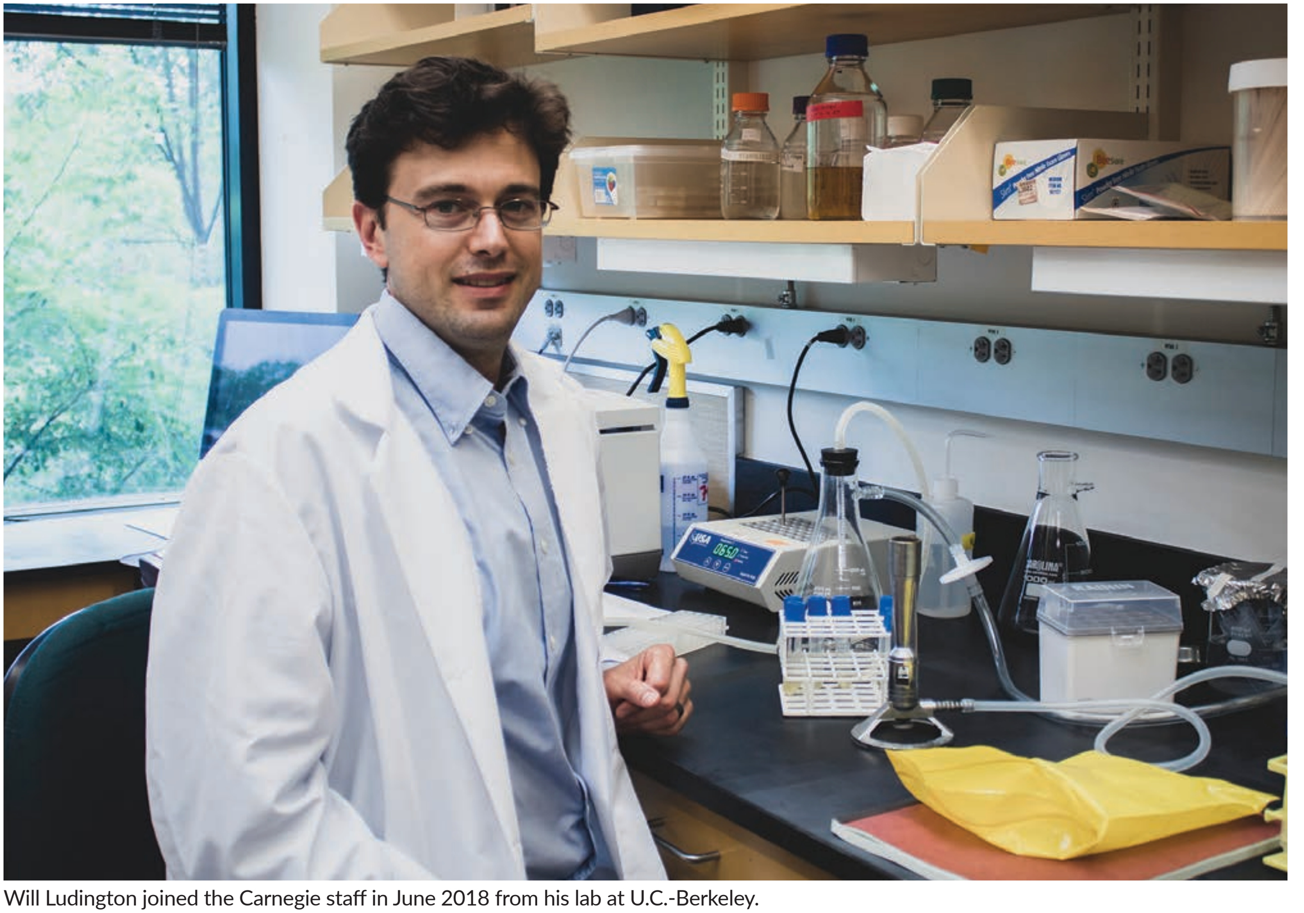
Evolutionary biologists have long probed how genes encode an individual's chances for success—or fitness—in a specific environment. To reveal a potential evolutionary trajectory, biologists measure the interactions among genes to see which combinations are most successful. An evolving organism should take the most successful path. This concept is called a fitness landscape, and various mathematical techniques have been developed to describe it. Like genes in a genome, gut microorganisms interact, but there has not been a widely accepted mathematical framework to map these ecological interaction patterns to host fitness.

To measure these complex interactions, Ludington and coworkers developed a new mathematical framework. They built a technique that describes the ecology of a microbiome, coupled to its host, by calculating the geometric structure of the interactions. Their mathematical method measures interactions in multidimensional space, where each species has its own dimension.

"Their ultimate goal is to use this predictive power to engineer the microbiome."

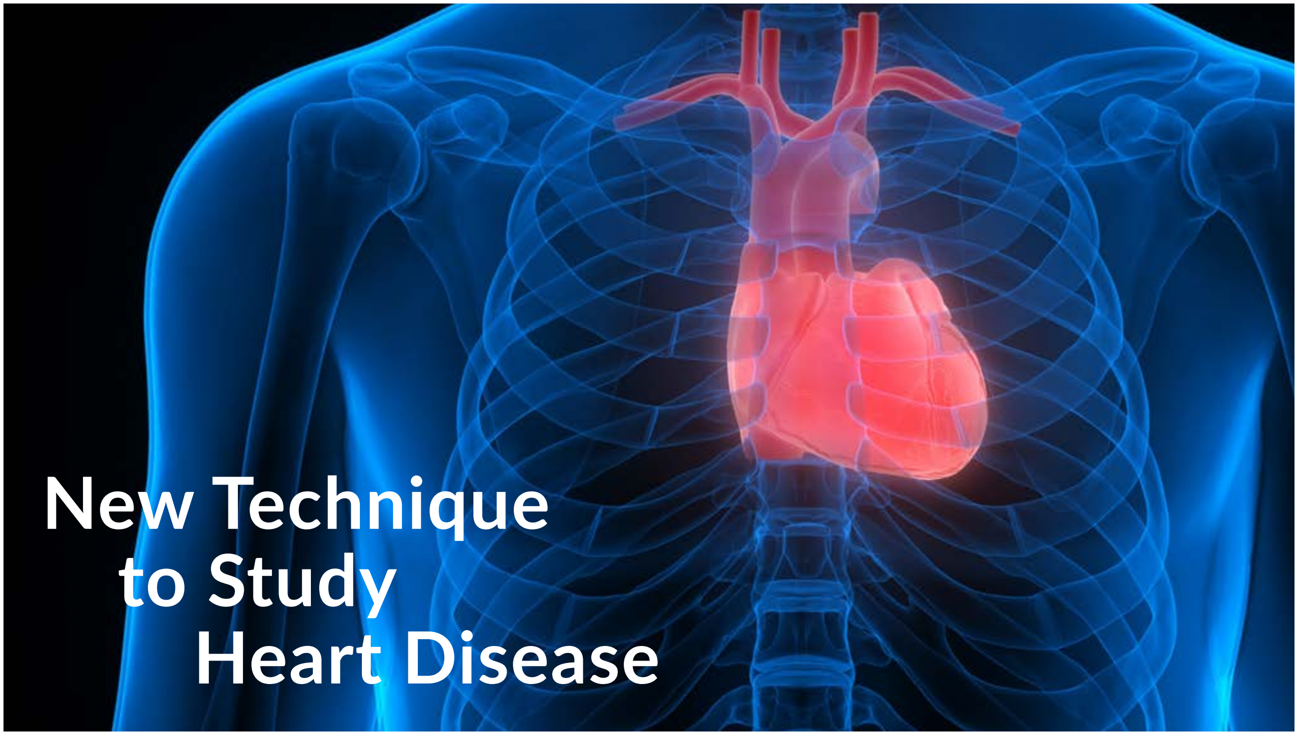
The team is now comparing different landscapes, which they hope will point to general principles of how microbial interactions affect host health. Ludington's next goals are to uncover molecular mechanisms by which hosts and their complex gut microbial communities interact. The multiscale approach connects the molecular interactions between microbes to the physiology of the whole animal. ■





Will Ludington joined the Carnegie staff in June 2018 from his lab at U.C.-Berkeley.

*Image courtesy Navid Marvi, Carnegie Institution for Science*



# New Technique to Study Heart Disease

## This approach is used to understand the cellular components. . . and to identify new drugs to fight cardiovascular disease.”

Heart disease and stroke are the leading cause of death worldwide. Steve Farber’s lab, with collaborators, has developed a new way to study the protein Apolipoprotein-B (ApoB) that shuttles lipids such as cholesterol and triglycerides (fat) around the circulatory system. These protein/lipid complexes, called lipoproteins, are the “bad cholesterols” that clog arteries and contribute to arterial disease. The new technique measures the number and size of lipoprotein particles, instead of the traditional cholesterol levels that can underestimate the risks. This approach is used to understand the cellular components needed to build these particles and to identify new drugs to fight cardiovascular disease.

The ApoB’s fat-and-cholesterol shuttling apparatus can clog blood vessels, forming dangerous plaque that can cause a heart attack. But ApoB is one of the largest protein complexes, making it difficult to study using traditional techniques. Farber lab’s James Thierer, a Johns Hopkins graduate student at the time of the study, developed the LipoGlo system in collaboration with the Mayo Clinic’s Stephen Ekker; they used cutting-edge genome engineering to tag zebrafish ApoB with a glowing enzyme similar to the one that lights up fireflies. This allows them to monitor the movement of ApoB lipid complexes in larval zebrafish, which are entirely transparent. Their approach is so sensitive it can be used to measure lipoproteins in less than a droplet of zebrafish blood, allowing researchers to perform tests usually performed in humans in tiny zebrafish larvae.

Because the larvae are entirely clear, researchers can localize these lipoproteins in an intact animal, which has not been done before. These studies revealed unexpected associations between lipoproteins and different structures and tissues that cannot be detected using traditional approaches.

The bright blue light (chemiluminescence) seen in these developing zebrafish is emitted by the NanoLuc protein in LipoGlo. The glowing enzyme is tagged to bad-cholesterol particles so researchers can visualize how much cholesterol is present in each fish and where it is located. The top image shows a 24-hour-old zebrafish embryo, with many cholesterol particles shown glowing from its large spherical yolk. Subsequent images were taken every 24 hours, indicating that cholesterol levels peak between three and four days of age.

*Image courtesy James Thierer and Ed Hirschmugl, Carnegie Institution for Science*

Johns Hopkins graduate student James Thierer (left) was lead author on the study. He performed the work with Steve Farber (right) and team. Thierer recently received his Ph.D.

*Image courtesy John Rawls*

Furthermore, the larval zebrafish is the only animal model conducive to high-throughput screening. One lab can breed thousands of zebrafish larvae each week, to potentially conduct thousands of experiments, such as screening collections of drugs to identify new potential treatments.

Using their system, Thierer and Farber also discovered that a mysterious gene, called *PLA2G12B*, has a huge impact on both the size and number of ApoB-containing lipoproteins. It is unclear how exactly this gene works, but intensive ongoing studies by the team point to its central role in packing lipids into lipoproteins before they are secreted into the bloodstream. Understanding the cell biology of this system may point to new strategies for treating heart disease. ■

# Thirty Years and Counting: Training Teachers and Students at the Carnegie Academy for Science Education (CASE)

These Washington, D.C., high school teachers are participating in the Professional Development Institute designed by Amgen Biotech Experience (ABE) and implemented by the Carnegie Academy for Science Education (above).

*Image courtesy Carnegie Academy for Science Education and Blonde Photography*

Thirty years ago Maxine Singer, then president of Carnegie, founded First Light, a free Saturday science school for middle school children in Washington, D.C. This launched the Carnegie Academy for Science Education (CASE) with the goal of encouraging interest in science and technology among students and teachers in Washington, D.C., public and charter schools. In 2017 CASE was selected to manage the new Amgen Biotech Experience (ABE) site in Washington, D.C. This year, ABE-D.C. established an extensive professional development program, with a rigorous biotechnology curriculum, including research-grade laboratory equipment loaned to D.C. high school teachers. First Light students, meanwhile, explored space, exoplanets, and rockets.

During the summer of 2018, 12 Washington, D.C., public high school science teachers were trained by CASE during a four-day Professional Development Institute. Throughout the 2018-2019 school year, these teachers, representing a third of the public D.C. high schools, borrowed the ABE-D.C. $20,000 research-grade lab kits to use in their classrooms for several weeks each. Approximately 500 students benefited from the program.

CASE high school interns compiled the ABE-D.C. lab kits and assisted during the Professional Development Institute. Some were highlighted in a video discussing equity in science labs. The video

Carnegie's NaDaizja Bolling (left) explains the $20,000 worth of scientific equipment included in the Amgen Biotech Experience-D.C. biotech kit to a science teacher in the program (right).

*Image courtesy Carnegie Academy for Science Education*

**Large Magellanic Cloud**
In this infrared image from NASA's Spitzer Space Telescope, the nearby dward galaxy resembles a fiery, circular explosion

These First Light students (right) test their egg drop "spacecraft" by dropping the craft from the stairs. The objective was to not break the egg. As part of the space curriculum, the students also used a NASA app to appear to space walk (above).
*Images courtesy Carnegie Academy for Science Education*

was viewed by over 18 ABE sites worldwide and was distributed through the CASE website.

This year First Light middle school students conducted research projects on space, explored the possibility of life on exoplanets, and constructed bottle rockets. Students learned about our place in the universe in several ways. Using cardboard tubes and diffraction grating, students explored how astronomers study objects in space using light, a technique called spectroscopy.

With little guidance, the students also chose different materials to design and construct egg drop "spacecrafts" to simulate the mechanics of landing on different worlds. Using a budget, students designed and built different crafts that would prevent the egg from breaking upon landing.

Students in the last term embarked on another project: designing and building bottle rockets with specific materials and instructions. They then competed to see which group's rocket went the highest. The winning rocket went some three stories high, and the winner was awarded space-themed "swag." First Light students also analyzed the viability of alien life in sci-fi and presented their research findings on exoplanets—planets outside of our Solar System—to families and friends. ■

At the end of the final First Light term, students launched their water bottle rockets in a competition. The winner with the highest rocket, which went some three stories, won some space "swag."
*Image courtesy Carnegie Academy for Science Education*


# Math for America

## Bolstering Master Teachers

In 11 years, Math for America DC (M*f*A DC) has reached over 30,000 Washington, D.C., public and public charter school students. It is affiliated with the national M*f*A program in New York City, founded in 2004 by mathematician and philanthropist James Simon to improve U.S. math and science education. M*f*A DC was founded by Carnegie President Emerita Maxine Singer to improve the mathematic achievement of D.C. students, and to prepare them for college and science and technical careers by enhancing math teacher training and professional development. M*f*A DC has two programs, the Teaching Fellowship and the Master Teacher Fellowship. This year, the Master Teacher Fellowship has been led by Bill Day, a former M*f*A DC master teacher and the 2014 D.C. Teacher of the Year.

The Teaching Fellowship ran from 2009-2014 and recruited, trained, and retained six cohorts of teaching fellows. The last cohort graduated in 2019. Thirty-seven fellows successfully completed the five-year program, which included earning a master's degree. Twenty-eight fellows are still teaching. Funding was provided by the National Science Foundation (NSF) Noyce Teaching Fellowship program, the Chancellor of the D.C. Public Schools, the D.C. Public Charter School Organization, and private sources.

The Master Teacher Fellowship, which began in 2011, is a five-year program for excellent secondary school mathematics teachers. The program includes stipends and financial support, plus leadership and

Sarah Bax (top) leads a professional development session. She was awarded the Presidential Award for Excellence in Mathematics and Science Teaching in 2011 and led the book club this past year. Will Stafford (bottom) led the video club to help master teachers apply for board certification. Stafford is board certified. Only 3% of the 3.7 million U.S. K-12 teachers have achieved board certification.

*Images courtesy Bianca Abrams, MfA DC*

professional development. The goal is to grow a core group of outstanding math teachers to remain in teaching. The program currently focuses on attracting particularly seasoned math teachers.

With the Teaching Fellowship ending, the Master Teacher Fellowship program is being enhanced with Day's "professional learning communities (PLCs)." These are support groups of math teachers who share ideas and instructional practices. One is a book club that shares books on motivating students. The other is a video production group to create videos required for applying for National Board Certification.

Bill Day (right) joined M*f*A DC to run the professional development program of the Master Teacher Fellowship program. He is a former M*f*A DC master teacher and the 2014 D.C. Teacher of the Year. Teaching fellows from cohorts five and six meet master teachers for professional development once a month (below).

*Images courtesy Bianca Abrams, MfA DC*

Sarah Bax, who was awarded the Presidential Award for Excellence in Mathematics and Science Teaching in 2011, leads the book club with Melissa Cohen, who is in her second year of the Master Teacher Fellowship program. Will Stafford leads the video club. He is board certified. Only 3% of the 3.7 million U.S. K-12 teachers are board certified. To further improve the quality of mathematics education, M*f*A DC encourages teachers to apply for this prestigious achievement. ■

2018-2019 YEAR BOOK

# Friends, Honors & Transitions

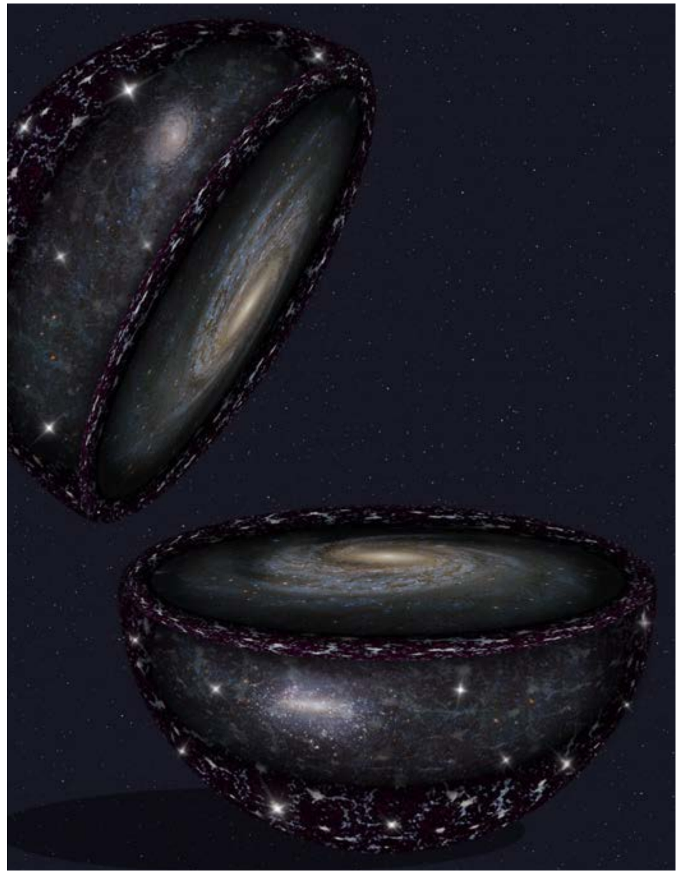
# Carnegie Friends

## Lifetime Giving Societies

Philanthropy has been the heart of Carnegie Science since Andrew Carnegie made his first gift of $10 million, which established the institution in 1902. Many generous individuals and foundations have since demonstrated a commitment to bold scientific pursuits that create new frontiers, expand human understanding, and launch the next generation of discoveries. We celebrate your investment in Carnegie Science, which helps our investigators' ability to explore beyond the boundaries of space, Earth, and life sciences. You've empowered Carnegie scientists with a rare ability to take risks and chart new—often, previously unimagined—research paths. Together, we are exploring new vistas of knowledge, and we are proud and thankful that you are our partner in this scientific enterprise.

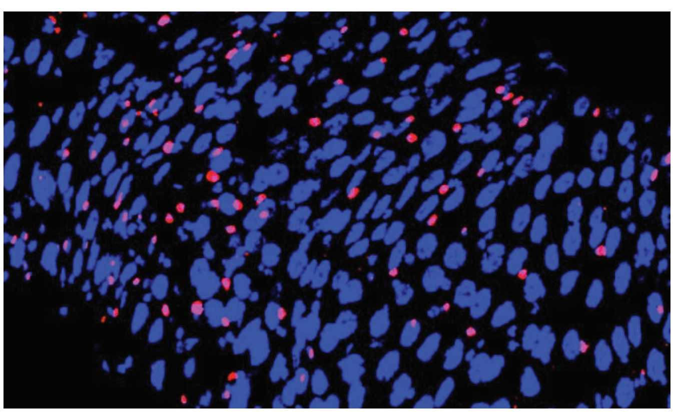
Your support has helped advance Carnegie's scientific research in areas as diverse as exploring the microbial ecosystems and cholesterol processing in the gut, to the effects of climate change on Earth's ecosystems, to how the large-scale structure of the universe is evolving and changing, plus much more.

The following listings include those who have generously supported Carnegie Science including individuals and those who have given from private foundations and donor-advised funds.



This artist's impression shows a cutaway of the parts of the universe to explore with the Sloan Digital Sky Survey-V (SDSS-V), led by Carnegie astronomer Juna Kollmeier. Millions of stars detected can allow the creation of a map of the entire Milky Way. Farther out, the survey can view the largest nearby galaxies. Even farther out, the survey can measure quasars—superbright objects powered by matter falling into giant black holes.

*Image courtesy Carnegie Institution for Science/Robin Dienel/SDSS*



The cellular structure of the intestine responds to specific nutrients in the diet. Here, a fruit fly gut is shown—each blue circle is the nucleus of an intestinal cell—which has doubled its normal number of hormone-producing cells (pink dots) following a diet high in cholesterol. Carnegie's Rebecca Obniski, Matthew Sieber, and Allan Spradling found changes in several tissues, showing they have long-lasting effects on metabolism and cancer susceptibility.

*Image courtesy Rebecca Obniski, Matthew Sieber, and Allan Spradling, Carnegie Institution for Science*

## The Carnegie Founders Society

When Andrew Carnegie made his original $10 million gift, he did so with the audacious goal of establishing an independent research organization that would increase scientific knowledge for the improvement of humankind. Likewise, members of the Carnegie Founders Society are visionaries who—through their generosity and entrepreneurial spirit—lay the foundations for innovation, ingenuity, and intellectual courage to thrive. Through their lifetime contributions of $10 million or more, these individuals have empowered scientists to pursue the most profound challenges in modern science and truly transform our relationship to the universe and world around us.

Caryl P. Haskins*
William R. Hewlett*
George Mitchell *

* Deceased

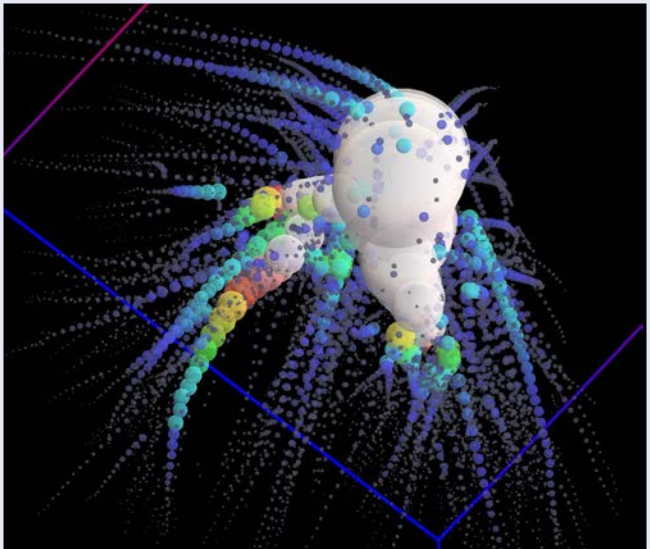
“These discoveries, we hope, will **educate and inspire future scientists** in years to come.”
Karen Hoffman, The Ahmanson Foundation

### Coming soon to a garage in Pasadena — the scientific lab of the future.

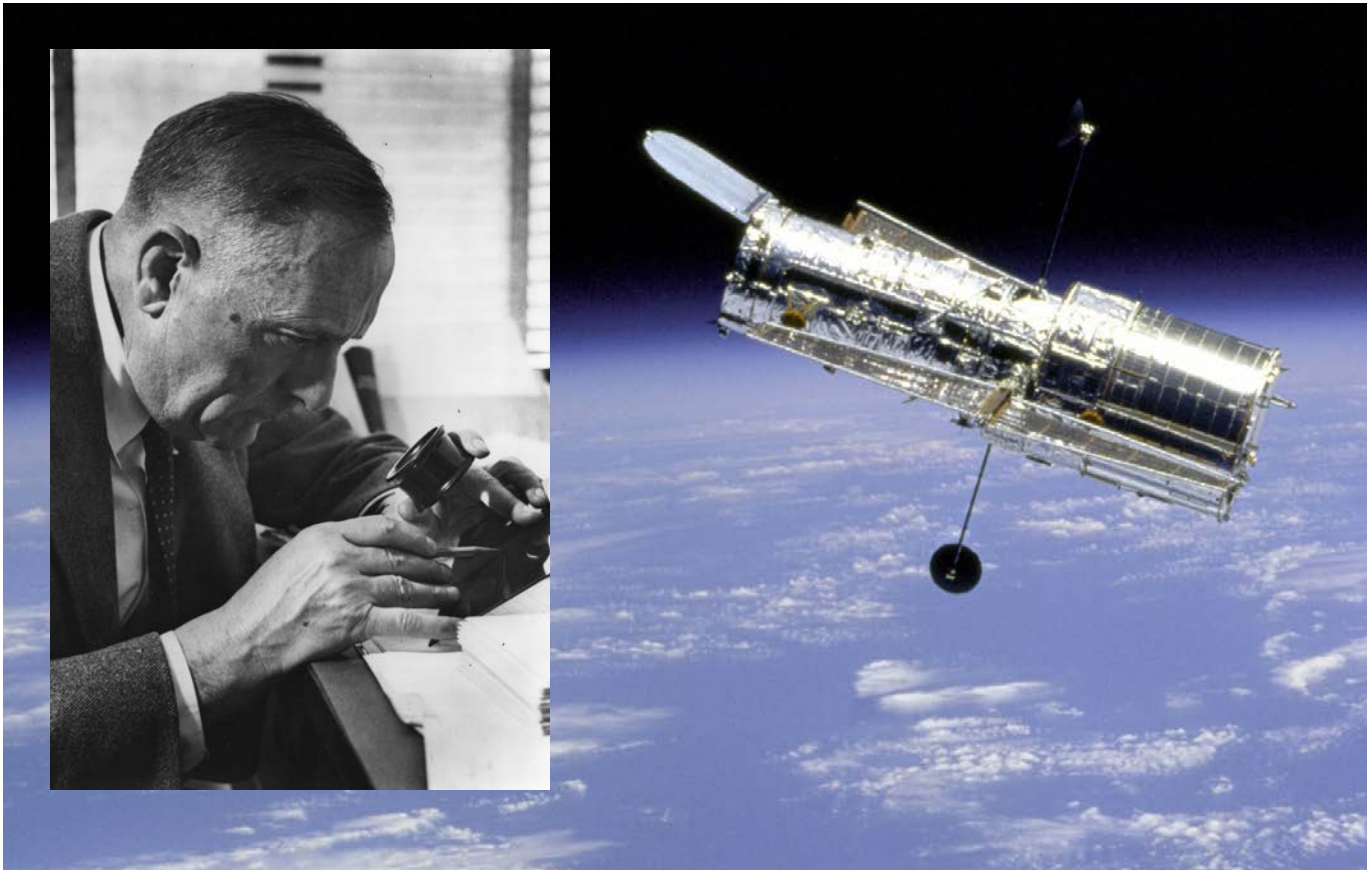
In recent years there has been an influx of available data for a rapidly growing number of astronomical objects rendering it impossible to rely on traditional analytical tools. The Viz Lab, generously funded by The Ahmanson Foundation, will give scientists a physical workspace where they can use cutting-edge computation and data-visualization techniques to actively interrogate data and answer some of the most exciting questions of our time.

The Viz Lab will be a collaborative space where scientists can work on both observed and simulated data displayed in full multi-dimensional representation. Carnegie’s astronomers and theorists will be able to compare unprecedented amounts of data about the most ancient galaxies in the universe with sophisticated computer simulations of galaxy formation. By analyzing observational data and theoretical models side by side, researchers will deepen our understanding of the complex dynamics that governed the birth and early evolution of the universe. The Viz Lab will also be used to help educate, engage, and ignite a passion for astronomy among the public and youth in Southern California.

In 2010, The Ahmanson Foundation made the first of two grants to support computational infrastructure at the Observatories—computer clusters that have resulted in faster, more advanced data collection and analysis. Carnegie astronomers are poised to solve some of the biggest mysteries of the cosmos. Karen Hoffman, Managing Director of the foundation, said, “We are pleased to assist Carnegie Observatories with the implementation of the Viz Lab and look forward to the results and discoveries it will yield on the evolution of the universe. These discoveries, we hope, will educate and inspire future scientists in years to come.”



Galacticus is a model used to determine the formation and evolution of the galaxies. Developed by Andrew Benson, staff astronomer, it is one of the most advanced models of galaxy formation available. This image shows a representation of a merger tree from one of Galacticus’ calculations. Each colored sphere represents a dark matter halo that grows with time and eventually merges with other dark matter halos.
*Image courtesy Andrew Benson*



The Hubble Space Telescope (right) was named after Carnegie astronomer Edwin Hubble, shown examining an astronomical plate in 1948.

*Images courtesy NASA and the Observatories of the Carnegie Institution for Science Collection at the Huntington Library, San Marino, California*

## The Edwin Hubble Society

Science often requires years of hard work and dedication before major discoveries can be made, and Edwin Hubble Society members make the critical investments that allow our scientists to take calculated risks in pursuit of new knowledge. Carnegie scientist Edwin Hubble, the most famous astronomer of the 20th century, shattered our old concept of cosmology by observing that the universe is vastly larger than we thought and is, in fact, expanding. We are proud to honor the members of the Edwin Hubble Society, who have fostered such extended, paradigm-changing research through their lifetime contributions of $1,000,000-$9,999,999.

Anonymous
D. Euan and Angelica Baird
William H. Gates III
William and Cynthia Gayden
Michael and Mary Gellert
Robert G. and Alexandra C. Goelet
William T. Golden*
Crawford H. Greenewalt*
David Greenewalt*
Margaretta Greenewalt*
Robert and Margaret Hazen
Margaret and Will Hearst
Richard E. Heckert*
Kazuo and Asako Inamori
Burton* and Deedee McMurtry
Jaylee and Gilbert Mead*
Cary Queen
Deborah Rose, Ph.D.
William J. Rutter
Thomas and Mary Urban
Sidney J. Weinberg, Jr.*
Michael G. & C. Jane Wilson~

* Deceased
~ New Member(s)

## The Vannevar Bush Society

Vannevar Bush, the renowned leader of American scientific research of his time, served as Carnegie's president from 1939 to 1956. Bush believed in the power of private organizations and the conviction that it is good for man to know. The Vannevar Bush Society recognizes those who have made lifetime contributions between $100,000 and $999,999.

Anonymous (5)
Philip H. Abelson*
Bruce and Betty Alberts
Mary Anne Nyburg Baker and
G. Leonard Baker, Jr.
Craig and Barbara Barrett~
Daniel Belin and Kate Ganz
Bradley F. Bennett*
Didier and Brigitte Berthelemot
David P. Brown*
Donald and Linda Brown
Richard Buynitzky*
A. James Clark*
Tom and Anne Cori
John Crawford
H. Clark and Eleanora K. Dalton*
John Diebold*
Jean and Leslie Douglas*
Herbert A. Dropkin
Michael A. Duffy
James Ebert*
Jo Ann Eder
Bruce W. Ferguson and
Heather R. Sandiford
Stephen and Janelle Fodor
Karen Fries and Richard Tait
Martin and Jacqueline Gellert
Sibyl R. Golden*
Diane Greene and
Mendel Rosenblum
Gary K. Hart and Cary S. Hart
Henrietta W. Hollaender*
Antonia Ax:son Johnson and
Goran Ennerfelt
Paul A. Johnson*
Paul and Carolyn Kokulis
Douglas E. Koshland~
Gerald D. and Doris* Laubach
Lawrence H. Linden
Michael T. Long
John D. Macomber
Steven L. McKnight
Richard A. and
Martha R. Meserve
J. Irwin Miller*
Al and Honey Nashman
Evelyn Stefansson Nef*
Alexander Pogo*
Elizabeth M. Ramsey*
Vera and Robert Rubin*
Allan R. Sandage*
Leonard Searle*
Allan Spradling
Frank N. Stanton*
Christopher and Margaret Stone
Dawn Taylor
David and Catherine Thompson
William* and Nancy Turner
Marshall Wais
Laure Woods

* Deceased
~ New Member(s)

## The Second Century Legacy Society

The Second Century Legacy Society recognizes individuals who make special commitments to Carnegie Science in support of scientific research and discovery through their wills, living trusts, estate plans, and other forms of planned giving. Members of this society carry on the vital tradition of philanthropy upon which Carnegie Science was founded, ensuring that throughout Carnegie's next 100 years we have the resources to broaden scientific knowledge and cultivate future generations of leading scientists. Through their planned gifts, members meet their charitable and financial goals while creating legacies that support the research areas most important to them. We gratefully acknowledge these dedicated supporters, whose impact will be felt in tomorrow's research advances.

Anonymous (4)~
Philip H. Abelson*
Paul A. Armond, Jr.
Liselotte Beach*
Bradley F. Bennett*
Francis R. Boyd, Jr.*
Lore E. Brown
Gordon Burley
Richard Buynitzky*
Eleanor Gish Crow*
H. Clark and Eleanora K. Dalton*
Hugh H. Darby*
Herbert A. Dropkin
Susan Farkas
Nina V. Fedoroff
Julie D. Forbush*
William T. Golden*
Crawford H. Greenewalt*
Margaretta Greenewalt*
David C. Hardy~
Mrs. P. Edgar Hare~
Gary K. Hart and Cary S. Hart
Caryl P. Haskins*
Robert and Margaret Hazen
Richard E. Heckert*
Henrietta W. Hollaender*
Paul A. Johnson*
Paul and Carolyn Kokulis
Mary G. Laufenberg~
Nancy Lee
Gilbert and Karen Levin
Chester B.* and Barbara C. Martin
Al and Honey Nashman
Charles J. and
Virginia E. Peterson
Alexander Pogo*
Elizabeth M. Ramsey*
Holly M. Ruess
Allan R. Sandage*
Leonard Searle*
Maxine and Daniel Singer
Frank N. Stanton*
Fay M. Stetzer*
Thomas H. B. Symons, C.C.
John R. Thomas, Ph.D.
Ian Thompson
Hatim A. Tyabji
William M. White
Robert and Roberta Young

* Deceased
~ New Member(s)

Michael Duffy (center holding toddler) is shown with his family at Disney World.
*Image courtesy Michael Duffy*

**Discovery science**—like the groundbreaking Earth, space, and life research done at Carnegie—is the knowledge capital that will help unlock the innovations and breakthroughs of tomorrow. I have supported Carnegie Science for more than ten years and hold a deep conviction about the role scientific inquiry plays in the improvement of humanity.

"We cannot forecast success in science, so we must allow our scientists to **follow the chain of discovery.**"

Michael Duffy

It is fascinating to me that we almost never know where the next amazing discovery is going to emerge. We cannot forecast success in science, so we must allow our scientists to follow the chain of discovery. Navigating through complex and divergent ideas can bring about these accomplishments, but one often experiences failure along the way—that is what discovery science is all about.

The flexibility and freedom that Carnegie provides its investigators allows them to pursue the next great discovery wherever it may lead. I want to ensure resources are available for maximum benefit across the institution—that is why I choose to make my gifts to Carnegie unrestricted. I trust the organization and its governance. I am confident in the institution's leadership and scientists, and I want to let Carnegie decide where the extra dollar is going to make the biggest impact.

It was Andrew Carnegie's vision to create an institution that finds the most promising scientific talent in order to conduct research with minimal barriers—and it is up to all of us to make sure this tradition lives on. Scientific progress has been the most potent source for human progress and supporting Carnegie has been my way of advancing that goal. I am proud to support the creativity and ingenuity of Carnegie investigators on their journey.

# Annual Giving

## The Barbara McClintock Society

*(Gifts received between July 1, 2018, and June 30, 2019)*

Annual contributions from generous individuals allow Carnegie Science's leadership to direct funds towards the most urgent needs and most promising research paths. They provide resources so that we can support investigators living at the forefront of bold scientific pursuits, such as Carnegie investigator Barbara McClintock, who won the Nobel Prize in Physiology/Medicine in 1983 for her work on patterns of genetic inheritance. We are thankful for the wonderful annual supporters, whose contributions are essential to sustain explorers like McClintock. With the McClintock Society, we recognize the generosity of donors who contribute $10,000 or more in a fiscal year.

**$1,000,000 or more**
William H. Gates III

**$100,000 to $999,999**
Anonymous (2)
Michael A. Duffy
Robert and Margaret Hazen
David and Catherine Thompson
Michael G. & C. Jane Wilson

**$10,000 to $99,999**
Anonymous
Craig and Barbara Barrett
David P. Brown*
Sigrid Burton and Max Brennan
Shashi Chawla
John Crawford
John P. de Neufville
Mona C. Figure
William and Cynthia Gayden
Donald Gellert and Elaine Koss
Michael and Mary Gellert
Robert and Rosa Gellert
Claire M. Haldan
Simon and Charlotte Harrison
Sandra Hess
Douglas E. Koshland
Michael T. Long
Robert and Bridget Lyons
Christopher and Lois Madison
Michael McCormick and Christine McCarthy
Elizabeth Moule and Stefanos Polyzoides
Charles J. and Virginia E. Peterson
Ray and Meredith Rothrock
Laura and Carlton Seaver
Ivan and Nina Selin
Marshall Wais
Matthew Weitzman

"Through Carnegie I am able to support basic research with the potential to open new paths of discovery."
Charles B. Hunter

**During World War II** my father worked at Carnegie's Department of Terrestrial Magnetism, and later at the Applied Physics Laboratory, helping to develop the radio proximity fuze; a technology which aided the United States and its allies in winning the war. Though he was at Carnegie for only a short time, I remember him expressing his pride at having worked alongside James Van Allen and his admiration for then-Carnegie president Vannevar Bush. After the war, he left physics and went into medicine and was an internist when I was growing up. His stories of working in physics and medicine instilled in me an intense curiosity for all areas of science and an appreciation for the importance of scientific discovery.

My father's history with Carnegie Science and the important research they were doing drew me to get involved with the organization. Over the years I've attended countless lectures hosted by Carnegie Science, and have always walked away with new ideas to ponder. I've met many of the scientists and gotten to know them and their work. They express an enthusiasm for Carnegie arising from the freedom they're given to pursue their interests and from the unique collegiality of the Carnegie community.

We are living in a time when scientific progress is essential to our survival and can help create a better world for future generations. Through Carnegie I am able to support basic research with the potential to open new paths of discovery. I know my money is going to support some of the brightest scientists, allowing them to pursue ideas that may transform our understanding of ourselves and the universe we live in.

## Other Individual Giving

Carnegie Science depends on and appreciates gifts at all levels and recognizes those who have contributed $9,999 or less this fiscal year. Thank you for your commitment.

**$1,000 to $9,999**

Anonymous (5)
Paul A. Armond, Jr.
Robert and Lynne Barker
Charlotte S. Barus
Richard and Kathleen Becker
L. Elizabeth Bertani
Gregory C. Board
Janet Rose and Eric Bosc
Peter C. Brockett and Laureen B. Chang
L. Taras Bryndzia
Stephen Charles
Cathy Colloff
Joseph H. and Alice Coulombe
Steven B. Crystal
Richard E. Cuellar
Igor Dawid and Keiko Ozato
William S. Dickey
Brack and Betty Duker
Jo Ann Eder
Sandra and Andrew Faber
William B. Fagan
Douglas M. Fambrough
Bruce W. Ferguson and Heather R. Sandiford
Jonathan Gainsley
Jeffrey M. Goecker
Thomas and Josephine Greeley
Diane Greene and Mendel Rosenblum
Tracy Hauri
Margaret and Will Hearst
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Rush D. Holt and Margaret Lancefield
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Theodore and Jacqueline Johnson
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Paul and Carolyn Kokulis
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Haozhe Liu
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Gary and Phoebe Mallard
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Dennis McKearin and Rosemarie Rinn
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Maxine and Daniel Singer
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Michael W. Thacher and Rhonda L. Rundle
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Peter Thompson
Elaine Tobin
Scott B. Tollefsen
Peter E. van Keken
Alan Wang
Mark Welsh
Stewart and Margaret Wills
Alice Rivlin* and Sidney Winter
David and Julianne Worrell
Robert and Roberta Young
Yixian Zheng

**Under $1,000**

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Judith Clark Adams
Grace Adamson
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Dorothy Alcorn
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Oscar Alvarado
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Jacqueline Apel
Juliette Appold
Terry J. Archambeault
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Lynnette Asselin
Karthika Audinet
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Joseph Azar
Aman Azhar
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Ray Bacorn
Lee Bailey
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Richard H. Ball
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Louis Barbier
Aimee Barciauskas
Phillip Barger
Yelyzaveta Bartholomew
Blair Bartlett
Gerald S. Barton
Ari Basen
Mazie Baskin
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Drew Bassini
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Emily Baxi
Philip Beachy and Katrin Andreasson
Cheryl Beale
George and Sonja Beall
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Michael Bedke
Richard Beggs
Robert and Bernice Beggs
Harvey E. Belkin
Peggy Bell
Lyndsay Benedict
Philip N. Benfey
Aldo and Janet Benini

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Theodore G. Benitt
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Shauna Bennett
Richard J. Bergemann
David Bergendorf
Sherrill Berger and
Robert Robinson
Larry Bergmann
Jill Bernier
Todd Bernstein
Frederick Bernthal and
Heather Lancaster
Charles Bestor
Matthew Bielik
Naheed Bilgrami
Sharon Billings
David Blackburn
Jillian Blades
Carlos Blanco and Susana Fredin
Jerzy Blusztajn
David Boldt and Lorna Schmid
Jack Bonner
Tom I. Bonner
John and Carol Boochever
Lorraine Boothby
Sharon Borden
Christian C. Borillo
Daniel H. Borinsky
Kurt R. Borski
Gerard Bouffard
Dirk Bouma
Philip Bourdillon and
Nancy Martin
Gabriel Bowen
William R. Bowser and
Mary A. O'Donnell
Heather Bradbury
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Dody and Tommy Brager
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Darren Braude
Lawrence Brenner and
Marsha Salus
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Scott Cameron
Mia Campbell
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Patricia Cappella
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Carol Laikin Carpenter
Matthew Carr
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Rebecca Chan
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Vandiver Chaplin
Michael Chappell
Phillip and Catherine Chatfield
Constance Chatfield-Taylor
Andrew Chen
Michael Chen
Wen-Ping Chen
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Glenn T. Chinery
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Kristofer Clark
Carolyn Cleveland
John Clinge
Mary Clive
Andrew Cocke
Michael P. Cohen
John R. and Annette W. Coleman
Maureen Coleman
E. William and
Catherine Colglazier
Christine Collins and
Dana Berliner
Ed Colloff
Albert S. Colman
Tamara Winter Compean
William Condell and
Susan Heineman
Nancy J. Cooksy
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Brandon Corkins
Luis Felipe Correa
James Correia
Roger and Mary Crain
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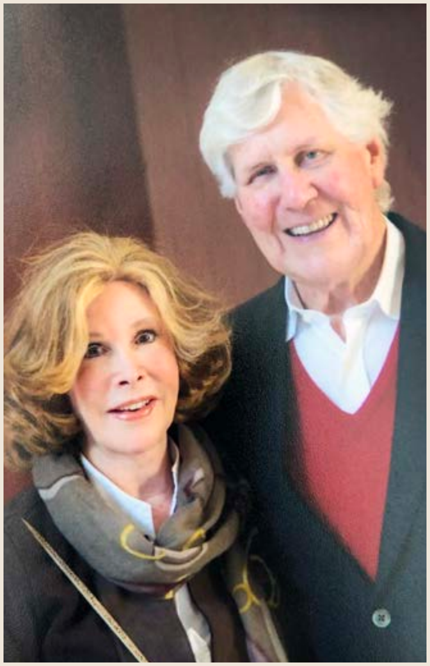
Dr. and Mrs. Daniel L. Crotty
Michael Crow
Mary Crowell
Craig and Sofia Crutchfield
Douglas G. Currie
Martin Czigler
John Dammann
Josh Daniell
Owen and Margo Davies
Andrew Davis
David M. Davis
John E. Davis and Bonnie Freeman
Nicholas F. Davis
Peter and Jacqueline Davis
Julius Day
Benjamin Dayman
Leonard Deerkoski
Kenneth De Graaf
Vannia De La Cuba
Louis Delair
David H. DeLeon
Wendy De Los Reyes
Luis del Pozzo
Campbell DeMallie and
Katherine Van Sickle
Eric Derks
Peggy Descamps
Salil Deshpande
Claudia Dessi
David H. and Kunie F. DeVorkin
Barbara O. de Zalduondo
John M. and Jane M. Dick
Kristine and Derek Dietz
John F. Dilley
Jonathan DiMartino
Matt Disen
Jacqueline E. Dixon
Minh Quan Do
William Doane
Sandro D'Odorico
Bruce R. Doe
Carl Dohrman
Andrew J. Dombard
Christopher Donahue
Lucia Donatelli
Scot Donato
Duane Donnell
Charles E. and Joan M. Dorgan
William and Nancy Doyle
Anne Drake
Stanley Dranginis
Elena Drei-Horgan
Martin Dresner
Arthur A. Drisko
Steve Dubois
Thomas S. Duffy
George Dunham
Janice Dunlap
Robert Dussault and Khanh Bui
Samuel and Barbara Dyer
David Dyregrov
Richard Earley
Gary Eastwick
Bradley Edelman
David H. Eggler

**Through Carnegie Science,** Bill and I have come to see how science can make the world into a wondrous place, and that understanding science doesn't have to be out of reach to the average person. We were invited to a small dinner with Carnegie Science after we made our first donation. We didn't expect much from the dinner—we assumed, actually, it might be quite dull—but after that night, we were captivated by science and the work of Carnegie.

At the dinner we sat with a few of the scientists and had an opportunity to talk with them directly about their work. I didn't know much about astrophysics at the time, and I remember being afraid, at first, to ask a question. But everyone was so friendly and welcoming that by the end of the night we walked away knowing we had found a supportive community where we could learn a little more about our world. It was an enthralling evening.

We were excited about all we were learning, so we made a few connections for Carnegie and invited our friends to learn more about the organization and its work. Time and time again we were impressed with how the scientists and researchers explained complex ideas—like looking back through deep space to the beginning of time—in a way that made clear sense. What we know and how we think about space and the universe has been transformed since we first became involved.

Some organizations stay out of the public sphere and we never hear from them, but Carnegie is different. Bill and I feel passionately that science and scientific research should be accessible to the public, exciting our imagination and growing our understanding of our world. It means so much to Bill and me that we have the opportunity to be a part of the fantastic work done here, and we are happy to give back in a small way through our support of Carnegie Science.



"...after that night, we were captivated by science and the work of Carnegie."

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“Carnegie allows their scientists to go where their curiosity takes them, and I believe **this is how science truly advances.**”

Nentcho Nentchev

**I grew up in Bulgaria** in a mountainous region with dry summer nights and little light pollution—and very few ways to entertain ourselves. So, at night, we would go outside and look up at the stars. That is really where my passion for astronomy began, looking up at the night sky and wondering. How could you look up and not wonder what is out there?

And that wonder grew as I got older, and I realized how little we know about our universe—and how much there is to discover. Though my career is not in astronomy, I wanted a way to stay connected to that curiosity and to help others who are doing the research.

I began to search for science nonprofits and chose Carnegie Science. The longevity and financial responsibility of the organization gave me confidence that my support is a lasting investment. But what really sets Carnegie apart is that I know by supporting a smaller organization, I can have a bigger direct impact. In some schools or research centers, the scientists are often beholden to a specific agenda and can’t deviate if the science is taking them in a different direction. But Carnegie allows their scientists to go where their curiosity takes them, and I believe this is how science truly advances.

Now I live in New York and when I look up at the sky, I can’t see the stars. But it gives me great pride and satisfaction to know that I am helping to support some of the smartest and brightest minds who are, themselves, peering up to answer some of the biggest questions humanity has ever known.

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Carnegies trustees, friends, and astronomers viewed the total eclipse of the Sun at Carnegie's Las Campanas Observatory in the high, dry Atacama Desert in Chile, on July 2, 2019.

*Image courtesy Milan Karol, Carnegie Institution for Science*

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William M. White

**In Memory of John Almquist**
Kathleen Taimi

**In Memory of Dorothy K. and Theodore J. Benitt**
Theodore G. Benitt

**In Honor of Davis J. and Mabel C. Bennett**
James D. Bennett

**In Memory of Francis R. Boyd**
Marguerite J. Kingston

**In Memory of Winslow Briggs**
Philip N. Benfey
William and Judith Eisinger
Sean Gallagher
Elaine Tobin
Zhiyong Wang and Yanli Yang

**In Memory of Louis Brown**
Louis G. Arnold
Lore E. Brown

**In Memory of Ruth Chiquet-Ehrismann**
Matthias Chiquet

**In Memory of Lauren Colloff**
Brent Allen
Cecelia R. Andrews
Sigrid Burton and Max Brennan
Cathy Colloff
Ed Colloff
Bryan and Phyllis Ellickson
Susan J. Holliday
Alice Mitchell
Melinda Risolo

**In Memory of James A. Cuellar**
Richard E. Cuellar

**In Memory of Gordon L. Davis**
Harvey E. Belkin

**In Memory of Dr. and Mrs. Russell J. Geibert and Mr. and Mrs. Thomas Philbin**
Michael Seibert

**In Memory of P. Edgar Hare**
Alison Brooks
Mrs. P. Edgar Hare

**In Memory of Erik Hauri**
Paula Antoshechkin
Laura H. Baim
Cheryl Beale
Peggy Bell
Jerzy Blusztajn
Sharon Borden
Darren Braude
L. Taras Bryndzia
Tami Burton
Patricia Cappella
Richard Carlson and Sonia Esperança
Nina Castilho Werneck De Castro
Carolyn Cleveland
John Clinge
Jacqueline E. Dixon
Anne Drake
Thomas S. Duffy

*continued on page 60*

*continued from page 59*

Janice Dunlap
Fran Finkelstein
Christine Franklin
Dale Friese
Susanne E. Garvey
Geophysical Laboratory, Carnegie Institution for Science
Gail Gomila
Arlene Graber
Helaine Groeger, on behalf of the PCWC Book Club
Robert Groman
Pauline Gruber
John Guy
Frank M. Gyngard
Monica R. Handler
Stanley R. Hart
Lawrence Hauri
Tracy Hauri
Eleanor Hillegeist
Munir and Jennifer L. Humayun
Frances E. Jenner
Teresa Kaczmarek
Milan M. Karol
Peter Kelly
Cheryl Kularatne
Jennifer Legge
Kerstin Lehnert
Marion Levine
Karen Lloyd
Wayne Lowrey
Adele Machata
Reiko Makabenta
Craig E. Manning
Brenda Mara
Anthony Mariano
Robert Mariano
Susan Martin
Mary McCaughey, on behalf of The Coffe Group
Maureen McNamara
Edward D. Mead
Thomas Meisel
William G. Minarik
Timothy D. Mock
Kay Mueller
Peng Ni
Mary Ann Noles
Maria Norberg
Julie A. O'Leary
Nancy Pflum
Aaron Pietruszka
Anastassia Pokrovski
Isabelle Roeth
David Ross
Jill Ross
Gloria Schneider
Tachibana Shogo
Michelle Smith
Alfred and Carol Spears
Christine Steinway
Jana Sterling Graber
Elizabeth A. Stevenson
Deborah Grace Steward
Donald Swanson
Frances Tesher
Bruce Toone
Dustin Trail
Lynne S. Vohsen
Evelyn Wagner
Lisa Watts
Cecily J. Wolfe
Fern Wolt
Richard Wysoczanski

**In Memory of Thomas Hoering**
David H. and Linda R. Freeman
Julia Sever Lytle

**In Memory of Edwin Hubble**
Dr. and Mrs. Daniel L. Crotty

**In Memory of Ray Juvelin**
Shan Hays

**In Memory of Alexandra K. Kielty**
Linda D. Kontnier

**In Memory of Chester B. Martin, Jr.**
Barbara C. Martin

**In Memory of Donald McClelland**
Robert McClelland
Karen J. Profet

**In Memory of Paul W. Merrill**
Léo Houziaux

**In Memory of Dr. J.N. Nanda**
Shashi Chawla

**In Memory of Paul Pollinger**
Holly Pollinger

**In Memory of Vera Rubin**
Sandro D'Odorico
Jo Ann Eder
Toby M. Horn
David C. Koo
George H. Pepper

**In Memory of Yvette Judith Sacks**
Stuart Sacks

**In Memory of Allan Sandage**
Steven R. Majewski

**In Memory of John G. Stoppa**
Christopher Stoppa

**In Memory of Thales**
James E. Williams

**In Memory of Dr. Sandra Wolman**
Eric Wolman

**In Memory of Lt. Col. Fredrick P. Woodson**
Karen Kertzner

**In Memory of Hatten S. Yoder, Jr.**
H. Richard Naslund

## Foundations and Corporations

**$100,000 to $999,999**
The Ahmanson Foundation
Paul G. Allen Philanthropies
Battelle
The Battery
The Ambrose Monell Foundation
Alfred P. Sloan Foundation

**$10,000 to $99,999**
The Abell Foundation, Inc.
American International Group, Inc.
The Herbert Bearman Foundation, Inc.
The Brinson Foundation
Carnegie Institution of Canada
Global Conservation
Richard W. Higgins Charitable Foundation
The McMurtry Family Foundation
The Kenneth T. and Eileen L. Norris Foundation
The Ralph M. Parsons Foundation
The Pfizer Foundation Matching Gifts Program
The Jean and Sidney Silber Foundation, Inc.
VISA

**$500 to $9,999**
Atlantis Research Foundation
Genentech, Inc.
Kramer Family Foundation
Maverick Capital Foundation
MonteCedro, Inc.
New England BioLabs, Inc.
O'Neil Family Foundation
Paul & Dottie Foundation of The DuPage Community Foundation
Honey Perkins Family Foundation, Inc.
The Rose Hills Foundation
Shell Oil Company Foundation
Smithsonian Institution
United Way of the Columbia-Willamette
The Walt Disney Company Foundation

The Carnegie-developed Quick Deploy Boxes (QDB) are rapidly deployable broadband seismic stations that are small and lightweight, low cost, and high performance. The device shown below was used for measurements at the Stromboli volcano off Sicily where Carnegie researchers (above) conduct fieldwork.

*Images courtesy Carnegie Institution for Science*

"We have enjoyed seeing . . .how this kind of long-standing relationship can influence the trajectory of basic science research."

*Jamie Bender, The Brinson Foundation*

**The Brinson Foundation started supporting seismology at Carnegie in 2007, and since that time has been an invaluable partner in our pursuit to develop the technology that may one day accurately forecast earthquakes and volcanic eruptions. Since the first grant to develop instrumentation for measuring continuous earthquake stress, Carnegie researchers have improved this technology, leading to the Quick Deploy Box (QDB), which is in use today. QDBs are rapidly deployable broadband seismic stations that are small and lightweight, low cost, and high performance.**

**Now, in their latest adaptation, the QDB technology will be used in combination with gravity experiments to study the correlation between seismic activity and gravity changes at one of the most active volcanoes in Chile. By measuring tiny shifts in gravity with extreme precision, the team can better understand how lava flows within the volcano, and potentially even predict the conditions that occur right before an eruption. This would be immensely helpful for early warning procedures and disaster preparedness.**

**"It has been a wonderful partnership," said Jamie Bender, senior program officer for The Brinson Foundation; "we have enjoyed seeing how the technology has evolved over the years and how this kind of long-standing relationship can influence the trajectory of basic science research."**

**The Brinson Foundation was established in 2001 to support education and scientific research that helps advance humankind, with a particular interest in supporting projects from early career scientists who are underfunded or not yet eligible to receive government funding. Carnegie Science is grateful for this longtime, dynamic partnership.**

# Honors & Transitions

★ Mary-Claire King

★ Steve Farber

★ Miguel Roth

★ Devaki Bhaya

## Honors

### Trustees and Administration

Trustee **Mary-Claire King** received the American Philosophical Society's (APS) Benjamin Franklin Medal for Distinguished Achievement in Science. King is renowned for her groundbreaking research in identifying the BRCA1 gene, which causes breast and ovarian cancer.

### Embryology

**Steve Farber** was recognized for science mentorship in May 2019 by New England Biolabs Inc. with its Passion in Science Award in the category of Mentorship and Advocacy. The company, which supplies research tools for sequencing, synthetic biology, and cellular and molecular research, launched the prize in 2014.

### Observatories

**Miguel Roth**, director of Carnegie's Las Campanas Observatory in Chile from 1990-2014 and then the representative of the Giant Magellan Telescope Organization (GMTO) in Chile, was awarded the Bernardo O'Higgins Order by the Chilean Foreign Affairs Ministry in Santiago. The award is the highest civilian honor for non-Chileans. It was given to him in recognition of his contributions to astronomy in Chile, and for his outreach in inspiring others to appreciate astronomy.

### Plant Biology

Carnegie's **Devaki Bhaya** was named a Fellow of the California Academy of Sciences in October 2018. She is one of 14 new members selected as "partners and collaborators in the pursuit of the Academy mission to explore, explain, and sustain life."

# Four More Postdoctoral Innovation and Excellence Awards

Carnegie's Postdoctoral Innovation and Excellence (PIE) Awards are made through nominations from the departments and are chosen by the Office of the President. The recipients are awarded a cash prize for their exceptionally creative approaches to science, strong mentoring, and contributing to the sense of campus community.

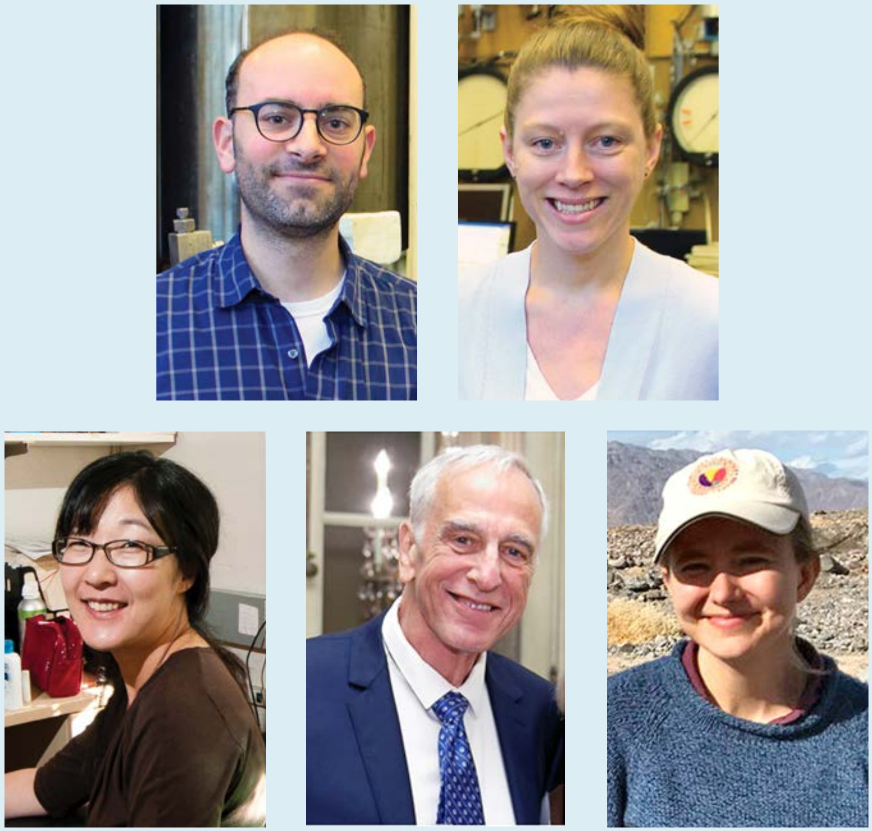
**Maria Drout**, the Observatories NASA Hubble Postdoctoral Fellow, received the 10th PIE Award for her scientific teamwork observing the first-ever glimpse of two neutron stars colliding, which was widely covered by the media and initiated a new era of astronomy. Additionally, Drout is dedicated to providing graduate students with the communication skills that they will need throughout their careers. Drout joined the faculty at the University of Toronto in September 2018.

**Ethan Greenblatt**, a senior postdoctoral associate at the Department of Embryology, received the 11th PIE Award for his major impact on biological science, particularly with his research identifying genetic factors underlying fragile X syndrome, the most common cause of autism. In addition, Greenblatt regularly contributes to the sense of department community and to the greater Baltimore community by mingling science with socializing, as a liaison between postdocs and the administration, and as a volunteer for BioEYES, a Carnegie-run hands-on science program for Baltimore City students and teachers.

**Heather Meyer**, a postdoctoral fellow at Plant Biology, was awarded Carnegie's 12th PIE Award for her pioneering work to identify the molecular mechanisms that plants use to sense and respond to seasonal temperatures in order to regulate flowering time and reproduction. She is also a leader in the Carnegie Institution Postdoc Association, organizes community events, and she co-organized and was an instructor for the Carnegie Writing Workshop about how to write and submit scientific papers.

**Meredith Wilson**, a postdoctoral associate at the Department of Embryology, was awarded the 13th PIE Award. Wilson investigated cellular processes regulating the absorption and transport of dietary fat in vivo using optically clear zebrafish larvae. She realized that zebrafish yolk can be a way to identify abnormalities in lipid processing and transport. She, with collaborators, identified a mutation in a protein essential for moving triglycerides and other lipids, which suggested a new strategy to develop treatments for diseases from elevated lipid levels. She also contributes to outreach and training for zebrafish courses including for BioEYES, the STEM outreach program based at Carnegie.

# Two New Venture Grants Awarded



Top shows Peter Driscoll (left) and Sally June Tracy.
From left to right at bottom are Sue Rhee, Joe Berry, and Jen Johnson.

*Images courtesy Carnegie Institution for Science*

The Office of the President selected two new Carnegie Venture Grants. **Peter Driscoll** of the Department of Terrestrial Magnetism and **Sally June Tracy** of the Geophysical Laboratory were awarded a Venture Grant for their proposal “Carbon-rich Super-Earths: Constraining Internal Structure from Dynamic Compression Experiments.” Plant Biology’s **Sue Rhee** and Global Ecology’s **Joe Berry** and **Jen Johnson** were awarded a Venture Grant for their project “Thermo-adaptation of Photosynthesis in Extremophilic Desert Plants.”

Carnegie Science Venture Grants ignore conventional boundaries and bring together cross-disciplinary researchers with fresh eyes to explore different questions. Each grant provides $150,000 support for two years, with the expectation of novel results. The grants are generously supported, in part, by trustee Michael Wilson and his wife Jane and by the Ambrose Monell Foundation.

# Transitions

## Trustees

In May 2019 the Carnegie Board of Trustees unanimously elected **Craig Barrett**, former president and chief executive officer of chip-maker Intel Corporation, as chairman of the Carnegie Board of Trustees. **David Thompson**, former president and chief executive officer of the global aerospace and defense company Orbital ATK, was unanimously elected as vice chair. They succeed outgoing cochairs **Stephen P. A. Fodor**, cofounder of the microarray technology company Affymetrix, and **Suzanne Nora Johnson**, former vice chairman of Goldman Sachs, and outgoing vice chair, **Bruce Ferguson**, president of the American University of Iraq, Sulaimani.

★ Craig Barrett

★ David Thompson

## Embryology

Staff associate **Kamena Kostova** joined the Department of Embryology in November 2018. She studies ribosomes, the factory-like structures inside cells that produce proteins, particularly the fundamental question of how cells respond when their ribosomes break down. She uses mass spectrometry, functional genomics methods, and CRISPR genome editing for this work. Kostova received a B.S. in biology from the Massachusetts Institute of Technology and a Ph.D. in biomedical sciences from the University of California, San Francisco. She was a recipient of a Fred Hutchinson Cancer Research Center 2018 Harold M. Weintraub Graduate Student Award.

★ Kamena Kostova

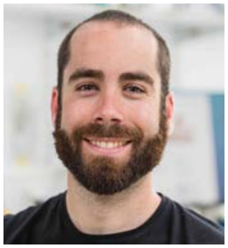
## Geophysical Laboratory

Staff scientist **Sally June Tracy** joined Carnegie in early 2019. She studies how crystallizing materials behave in extreme environments to understand the fundamental physical behavior of materials under high-pressure and high-temperature conditions. Tracy uses dynamic compression techniques with high-energy X-ray sources at conditions that mimic impacts and the interiors of terrestrial and exoplanets. Tracy received her B.A. in physics from Occidental College and both a master's and a Ph.D. in materials science from the California Institute of Technology. She was a postdoctoral scholar at Princeton University prior to Carnegie.

★ Sally June Tracy

## Plant Biology

Evolutionary geneticist **Moises Exposito-Alonso** joined Carnegie as a staff associate in 2019. He investigates how plants will evolve to keep pace with climate change with large-scale ecological and genome-sequencing experiments and computational methods to forecast evolutionary outcomes of potential future biodiversity losses. He is also interested in developing genome engineering methods to help species adapt. Exposito-Alonso earned a B.S. in biology from the University of Seville, an MSc in quantitative and population genetics from the University of Edinburgh, and a Ph.D. in ecological genomics from the Max Planck Institute in Tübingen. He was also a postdoctoral fellow at the University of California, Berkeley.



★ Moises Exposito-Alonso

2018-2019 YEAR BOOK

# Financial Profile

*for the year ending June 30, 2019*

**READER'S NOTE:** *In this section, we present summary financial information. Each year the Carnegie Institution, through the Audit committee of its Board of Trustees, engages an independent auditor to express an opinion about the financial statements and the financial position of the institution. The complete audited financial statements are made available on the institution's website at www.CarnegieScience.edu.*

The Carnegie Institution for Science completed fiscal year 2019 in sound financial condition after generating a net return of 4.8% on the diversified investments within its endowment; maintaining a disciplined spending policy that balances today's needs with the long-term requirements of the institution and the interests of future scientists; and the continued support of organizations and individuals who recognize the value of basic science.

The primary source of support for the institution's activities continues to be its endowment. This reliance on institutional funding provides an important degree of independence in the research activities of the institution's scientists.

As of June 30, 2019, the endowment was valued at $966 million. Over the period 1998-2019, average annual distributions from the endowment to the budget were 5.0%. Carnegie closely controls expenses to ensure the continuation of a healthy scientific enterprise.

For several years, under the direction of the Investment committee of the board, Carnegie's endowment has been allocated among a broad spectrum of asset classes including: equities (stocks), absolute return investments, real estate partnerships, private equity, natural resources partnerships, and fixed-income instruments (bonds). The goal of this diversified approach is to generate attractive overall performance and reduce the volatility that would exist in a less diversified portfolio. In 2016 Carnegie hired its first Chief Investment Officer to more proactively steward the endowment's assets.

The Chief Investment Officer and Investment committee regularly examine the asset allocation of the endowment and readjust the allocation, as appropriate. The institution relies upon external managers and partnerships to conduct the investment activities, and it employs a commercial bank to maintain custody. The following chart shows the allocation of the institution's endowment among asset classes as of June 30, 2019.

| Asset Class | Target | Actual |
|---|---|---|
| Common Stock | 38.0% | 35.6% |
| Alternative Assets | 52.0% | 56.3% |
| Fixed Income and Cash | 10.0% | 8.1% |

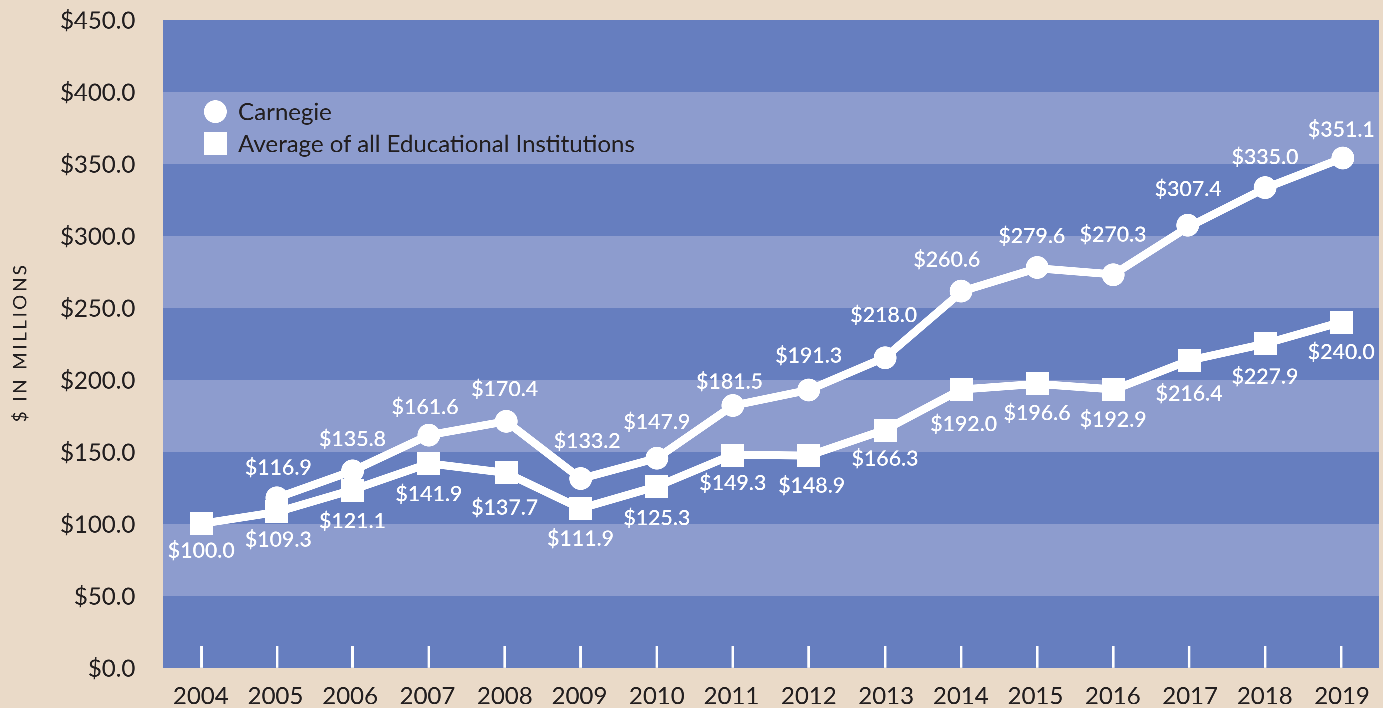
Carnegie's investment goals are to provide high levels of current support to the institution and to maintain the long-term spending power of its endowment. The success of Carnegie's investment strategy is illustrated in the first figure (right) that compares, for a hypothetical investment of $100 million, Carnegie's investment returns with the average returns for all educational institutions for the last 15 years.

Carnegie has pursued a long-term policy of controlling its spending rate by using a hybrid spending rate, which in the long term contributes 5% of the endowment for annual use. Carnegie employs what is known as a 70/30 hybrid spending rule. That is, the amount available from the endowment in any year is made up of 70% of the previous year's budget, adjusted for inflation, and 30% of the most recently completed year-end endowment value, multiplied by the spending rate of 5% and adjusted for inflation and debt. This method reduces volatility from year-to-year. The second figure (right) depicts actual spending as a percentage of ending market value for the last 20 years.

In fiscal year 2018, Carnegie benefitted from continuing federal support. Carnegie received $19.89 million in new/additional federal grants in 2019. This is a testament to the high quality of Carnegie scientists and their ability to compete successfully for federal funds in this period of fiscal restraint.

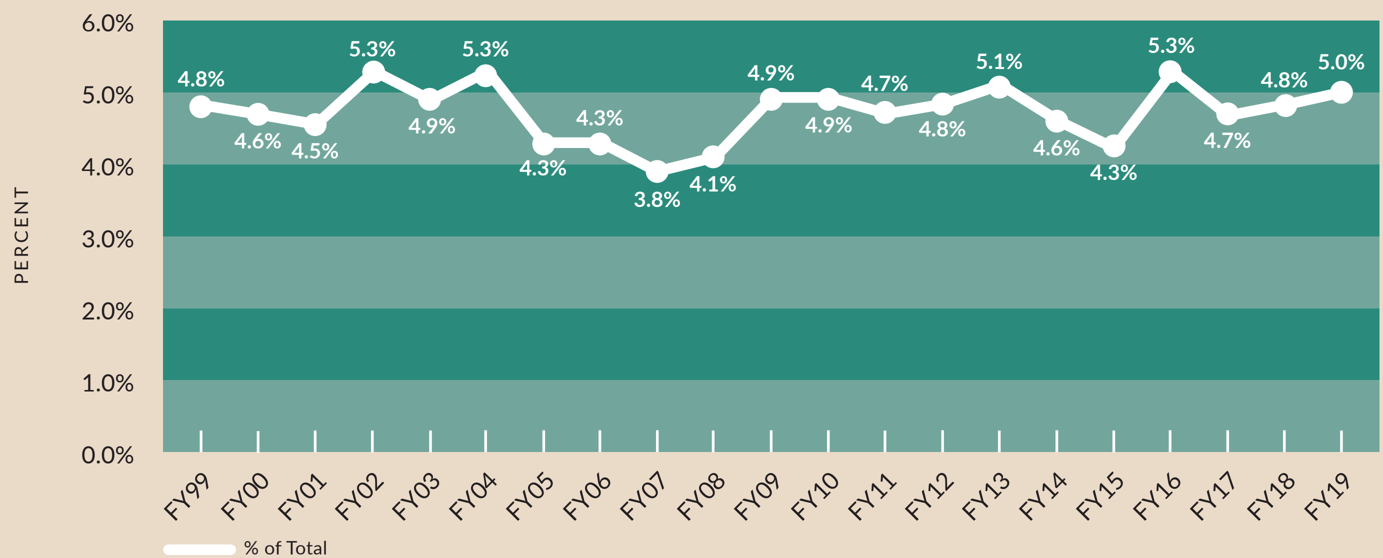
Carnegie also benefits from generous support from foundations and individuals. In 2019, Carnegie brought in $7.9 million in funding from foundations/non-federal entities, which was a $300,000 increase over 2018. Within Carnegie's endowment, there are several "funds" that provide support either in a general way or targeted to a specific purpose. The largest of these is the Andrew Carnegie Fund, begun with the original gift of $10 million. Mr. Carnegie later made additional gifts totaling another $12 million during his lifetime. This tradition of generous support for Carnegie's scientific mission has continued throughout our history and a list of donors in fiscal year 2019 appears in an earlier section of this *Year Book*. In addition, Carnegie receives important private grants for specific research purposes.

## Illustration of $100 Million Investment — Carnegie Returns vs. Average of all Educational Institutions (2004 - 2019)




Average returns for education institutions are taken from the NACUBO endowment study.

## Endowment Spending Rate as a Percent of Endowment Value



# Statement of Financial Position

July 30, 2019, and 2018

*(in thousands)*

| | 2019 | 2018 |
|---|---|---|
| **Assets** | | |
| Cash and cash equivalents | $ 33,050 | $ 18,761 |
| Contributions receivable | 3,750 | 3,848 |
| Accounts receivable and other assets (net) | 7,743 | 7,307 |
| Bond proceeds | 21,661 | 21,306 |
| Investments | 953,113 | 996,497 |
| Property and equipment (net) | 126,641 | 132,309 |
| Long-term deferred asset | 60,460 | 59,324 |
| **Total assets** | **$ 1,206,418** | **$ 1,239,352** |
| **Liabilities** | | |
| Accounts payable and accrued expenses | 12,069 | 13,706 |
| Deferred revenue | 26,828 | 27,504 |
| Bonds payable | 115,032 | 115,038 |
| Accrued postretirement benefits | 27,721 | 24,281 |
| Total liabilities | 181,650 | 180,529 |
| **Net Assets** | | |
| Without donor restriction | 311,622 | 322,559 |
| With donor restriction | 713,146 | 736,264 |
| Total net assets | 1,024,768 | 1,058,823 |
| **Total liabilities and net assets** | **$ 1,206,418** | **$ 1,239,352** |

# Statement of Activities

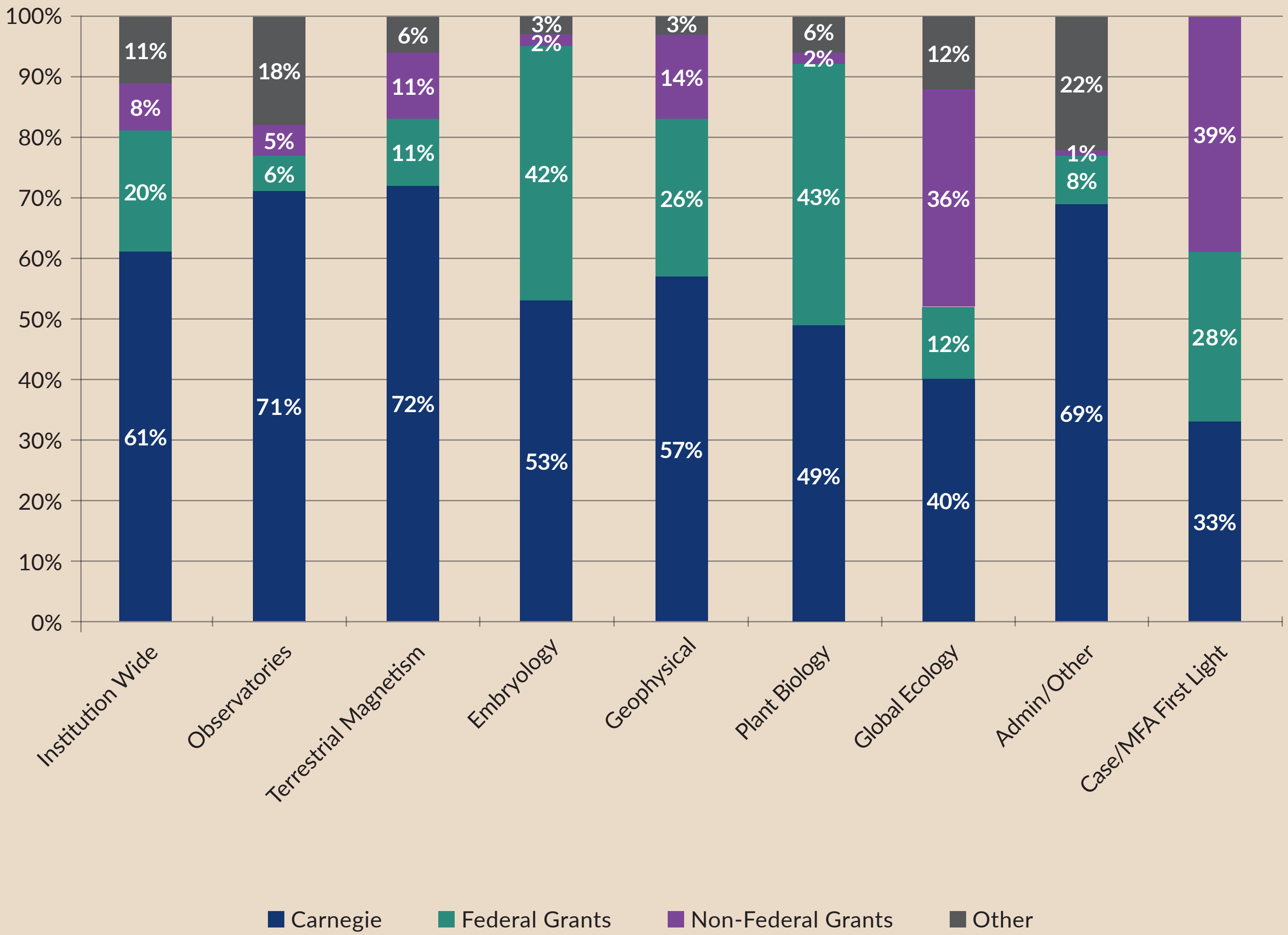
July 30, 2019, and 2018

*(in thousands)*

| | 2019 | 2018 |
|---|---|---|
| **Revenue and Support** | | |
| Grants and contracts | $ 20,526 | $ 26,907 |
| Contributions, gifts | 7,987 | 7,681 |
| Other Income | 7,559 | 4,232 |
| **Net External Revenue** | **36,072** | **38,820** |
| Investment income and unrealized gains | 31,221 | 95,665 |
| **Total Revenue** | **$ 67,293** | **$ 134,485** |
| **Expenses** | | |
| Program and Supporting Services: | | |
| Terrestrial Magnetism | 10,039 | 9,882 |
| Observatories | 23,055 | 22,886 |
| Geophysical Laboratory | 13,294 | 19,711 |
| Embryology | 14,697 | 12,764 |
| Plant Biology | 9,360 | 10,118 |
| Global Ecology | 7,123 | 6,944 |
| Other programs | 1,013 | 849 |
| Administration and general expenses | 14,968 | 13,478 |
| **Total Expenses** | **$ 93,549** | **$ 96,632** |
| Change in net assets before pension related changes | (26,256) | 37,853 |
| Pension related changes | (2,611) | 1,773 |
| Grant modifications | (5,188) | — |
| Net assets at the beginning of the period | 1,058,823 | 1,019,197 |
| **Net assets at the end of the period** | **$ 1,024,768** | **$ 1,058,823** |

## Expenses by Funding Type by Department





# Small Size, Long Reach

**Some 60 senior Carnegie investigators, with postdoctoral fellows and other colleagues, machinists, business administrators, facilities staff, and more contributed to more than 680 papers published in the most prestigious, peer-reviewed scientific journals during the last year. Many discoveries were widely covered by the media and had extensive social media reach.**

**For a full listing of personnel and publications see https://carnegiescience.edu/yearbooks**

# Carnegie Investigators IN THE NEWS



"It is definitely a very substantial step ahead… I think it's quite conclusive, it is metallic."

ALEXANDER GONCHAROV **SCIENCE NEWS**

"Normally, I can see San Francisco Bay from my home. Today and for the past few days, I could not see the bay for all the smoke from the Paradise fire. Fires that approach the size of the Paradise fire are most common in the hot dry years - the kind of years that we are likely to see many more of."

KEN CALDEIRA **THE WASHINGTON POST**

"It's the Solar System's most distant object. Orbiting 11 billion miles from the Sun, this tiny world offers additional clues in the search for the proposed Planet Nine."

SCOTT SHEPPARD **THE NEW YORK TIMES**

"In plants, this genetic isolation can be maintained by features that prevent the 'male' pollen of one species from successfully fertilizing the 'female' pistil of another species."

MATTHEW EVANS **PHYS.ORG**

"The team…was examining the meteorite when—completely by accident—they found a tiny section that appeared to be a comet's building block. This would mean a bit of space dust that originated from comets… somehow got captured and encased by an asteroid."

LARRY NITTLER **NEWSWEEK**

“The exotic objects would have been thoroughly mixed with the more abundant solar system materials and we would be hard-pressed to detect the isotopic anomalies,” he says.

CONEL ALEXANDER **SCIENTIFIC AMERICAN**

“We're interested in understanding the cellular processes that maintain those preferential relationships. We also want to know if it's possible that more heat tolerant, non-preferred algae could revive bleached coral communities...”

ARTHUR GROSSMAN **SCIENCE DAILY**



“Researchers at the Deep Carbon Observatory say the diversity of underworld species bears comparison to the Amazon or the Galápagos Islands, but unlike those places the environment is still largely pristine because people have yet to probe most of the subsurface.”

ROBERT HAZEN **WIRED**

“We need a better understanding of how a planet's composition and interior influence its habitability, starting with Earth. This can be used to guide the search for exoplanets and star systems where life could thrive, signatures of which could be detected by telescopes.”

ANAT SHAHAR **UPI**

“With further studies, Juna Kollmeier, an astronomer at the Carnegie Institution ... and Sean Raymond, an astronomer from the University of Bordeaux hope to discover the reason why our Moon does not have a moonmoon.”

JUNA KOLLMEIER **FORBES**

“‘Caldeira thinks that cutting emissions is more like trying to kick a bad habit. ‘Stopping sooner is always better than stopping later,’ he said. ‘But it is never too late to stop.’”

KEN CALDEIRA **THE LOS ANGELES TIMES**


CARNEGIE SCIENCE
THE OBSERVATORIES
CARNEGIE INSTITUTION OF WASHINGTON

« THE OBSERVATORIES »

# Astronomy

Observatories' staff, Pasadena, CA (kneeling on right, from left to right): Dan Kelson, Charlie Hull, Scott Rubel. First row (from left) Jerson Castillo, Luis Ochoa, Leon Aslan, Xialong Du, Stefanie Wachter, Gwen Rudie, Ian Thompson, Sharon Kelly, Alicia Lanz, Christoph Birk, Erica Clark, Kristi Macklin, Barry Madore, Josh Simon, Andrew Newman, John Mulchaey, Andrew Benson, Sung Ri Sok, Stephen Shectman, Alan Dressler, Beverly Fink, Irina Strelnik. Second row: Shannon Patel, Earl Harris, Sharon Wang, Alex Ji, Decker French, Tom Cooper, Pavaman Bilgi, Tom Connor, Becky Lynn, Rosalie McGurk, Shuvo Uddin, Louis Abramson, Paul Collison, Andy McWilliam, Tony Piro, Alan Uomoto, Jeff Rich, Kit Whitten, Jeff Crane.

## Carnegie Investigators

**Staff Scientists**

ANDREW BENSON
REBECCA BERNSTEIN
ALAN DRESSLER, Staff Member Emeritus
JUNA KOLLMEIER
NICHOLAS KONIDARIS
PATRICK MCCARTHY
ANDREW MCWILLIAM
JOHN MULCHAEY, Director
ANDREW NEWMAN
AUGUSTUS OEMLER, JR., Director Emeritus
ERIC PERSSON, Staff Member Emeritus
ANTHONY PIRO
GEORGE PRESTON, Director Emeritus
MICHAEL RAUCH
GWEN RUDIE
FRANÇOIS SCHWEIZER, Staff Member Emeritus
STEPHEN SHECTMAN
JOSHUA SIMON
IAN THOMPSON
RAY WEYMANN, Director Emeritus

**Research Associates**

CHRISTOPHER BURNS, Research Associate
JEFFREY CRANE, Staff Associate
DAN KELSON, Staff Associate
BARRY MADORE, Senior Research Associate Emeritus [1]

**Las Campanas Research Staff**

LEOPOLDO LIRA INFANTE, Director, Las Campanas Observatory
DAVID OSIP, Associate Director, Las Campanas Observatory
MARK PHILLIPS, Director Emeritus, Las Campanas Observatory

**Las Campanas Resident Astronomer**

NIDIA MORRELL, Resident Astronomer

[1] To December 31, 2018, retired



« LAS CAMPANAS »

Chilean staff—mountain (left, first row left to right): Edgar Véliz, Danilo González, Hugo Rivera, Juan Carrasco, Erwin Guerra, Angélica León, Patricio Pinto, Francesco di Mille, Gastón Gutiérrez, Gabriel Prieto. Second row: Miguel Ocaranza, Carlos Godoy, Manuel Millar, Nelson Ibacache, Konstantina Boutsia, Michael Vicencio, Jorge Rojas, Felipe Besser, Marcelo Rodriguez, Osvaldo Ponce, Héctor Balbontín, Francisco Mery, Povilas Palunas, Juan Gallardo.

Chilean staff—El Pino (right, first row from left to right) Javiera Rey, Daniel Briones, Silvia Muñoz, Nelda Juica, Reinaldo Vega, Herman Rojas, Juan Carrasco, José Lizardi. Second row: Iván Barraza, Javier Escobar, Jilberto Carvajal, Jonathan Medalla, Enrico Congiu, Roberto Bermúdez.

## Carnegie Investigators

**Staff Members**

- **ALEX BORTVIN**
- **DONALD D. BROWN, Director Emeritus**
- **CHEN-MING FAN**
- **STEVEN A. FARBER**
- **JOSEPH G. GALL**
- **MARNIE E. HALPERN**
- **WILLIAM LUDINGTON**
- **ALLAN C. SPRADLING, Director Emeritus**
- **YIXIAN ZHENG, Director**

**Staff Associates**

- **KAMENA KOSTOVA**[1]
- **CHRISTOPH LEPPER**[2]
- **ZHAO ZHANG**

[1] From November 1, 2018
[2] To September 28, 2018

« THE DEPARTMENT OF EMBRYOLOGY »

# Genetics/Developmental Biology

First row (from left): Parker Sinclair, Michelle Biederman, Daria Naumova, Liangji Li, John Urban, Jiaxiang Tao. Second row: Ed Hirschmugl, William Ludington, Allan Spradling, Yixian Zheng, Kamena Kostova, Steven Farber, Joseph Gall, Marnie Halpern, Donald Brown, Cheng-Ming Fan, Julia Baer, Mackenzie Klemek. Third row: Maggie Shen, Darby Kozan, Terrone Jasper, Jeremy Hayes, Nathalie Gerassimov, Anwen Shao, Yun Bai, Kun Dou, Ran Zhou, Allison Pinder, Lynn Hugendubl, Chiara DeLuca, Jung-Hwa Choi, Svetlana Deryusheva, Frederick Tan, Joseph Tran, Lauren Gilmer. Fourth row: Semen Vlasov, Marcia Edwards, Wilbur Ramos, Eugenia Dikovsky, Valerie Butler, Michael Sepanski, Sammasia Wilson, Devance Reed, Carol Davenport, Jean-Michael Chanchu, Ethan Greenblatt, Wesley Yon, Maria Jaime, Karina Gutierrez Garcia, Melissa Keinath, Marla Tharp, Meredith Wilson, Tabea Moll, Daniel Martinez, Ashish Kumar Tiwary, Vladimir Shiriagin. Last row: Chenhui Wang, Robert Vary, Ted Cooper, Mahmud Siddiqi, Robert Levis, Rick Vader, Steven DeLuca, Lu Wang, Haolong Zhu, Ji Cheng, Ren Dodge, Minjie Hu, Michelle Macurak, Jared Akers, Jen Anderson.

# Earth/Planetary Science and Astronomy

First row (from left): Maximilien Verdier-Paoletti, Fouad Tera, Kei Shimizu, Tri Astraatmadja, Wan Kim, Richard Carlson, Michael Acierno, Brian Schleigh, Andrea Patzer. Second row: Cian Wilson, Mary Ferranti, Adriana Kuehnel, Helen Janiszewski, Steven Golden, Shi (Joyce) Sim, Hélène Le Mével, Kathleen McKee, Janice Dunlap, Quintin Miller. Third row: Steven Shirey, Daniel Portner, Diana Roman, Parvin Zahedivash, Lara Wagner, Shaun Hardy, Tim Mock. Fourth row: (visiting researcher) Arto Luttinen, Jaehan Bae, Matthew Clement, (visiting researcher) Tetsuya Yokoyama. Fifth row: Susana Mysen, Jianhua Wang, Scott Sheppard, Doug Hemingway, John Chambers, Alan Boss, Kevin Johnson, Bill Key, Mattie Burris.

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[1] To September 5, 2018, deceased



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SALLY JUNE TRACY[2]
MICHAEL WALTER, Director

[1] To December 31, 2018
[2] From January 7, 2019

« THE GEOPHYSICAL LABORATORY »

# Matter at Extreme States, Earth/Planetary Science

First row (from left): Olivier Gagné, Amol Karandikar, Aline Niyonkuru, Wan Si Tang, Suzy Vitale, Asmaa Boujibar, Michael Walter, George Cody, Douglas Rumble III, Robert Hazen, Timothy Strobel, (visiting researcher) Kalin Tasca. Second row: (machine shop intern) Chase Power, Irina Chuvanova, Nico Kuetter, (visiting researcher) Catharine Conley, (visiting researcher) Nicole Nie, Yunxiu Li, Joy Buongiorno, Ronald Cohen, (visiting researcher) Yuan Yin, Jeff Lightfield, Victor Lugo. Third row: Dionysis Foustoukos, Mary Ferranti, Alycia Alexander, Jing (Jill) Yang, Andrew Steele, Shaun Hardy, Emma Bullock, Li Zhu, Shuang Zhang, Kai Luo. Fourth row: Yingwei Fei, Bjørn Mysen, Dyanne Furtado, Peng Ni, Jennifer Mays, Yanhao Yin, Lin Wang, Craig Schiffries. Fifth row: Anat Shahar, Seth Wagner, Andrea Mangum, Zackary Geballe, Joseph Lai, Gabor Szikagyi, Javier Rojas, (visiting researcher) Austin Gion, Trong Nguyen, Troy Walthour.

# Global Ecology

First row (from left): Lei Duan, Wu Sun, Terri Tippets, Naoia Williams, Evana Lee, Kim Poon, Ngoc Ho. Second row: Tristan Ballard, Bingwen Qui, Nina Randazzo, Jessie Chen, Diane Chermak, Joe Berry. Third row: Enrico Antonini, Nienke Besbrugge, Karine Prado, Clare Tuma, Geeta Persad, Anna Michalak, Danny Cullenward. Fourth row: Ken Caldeira, David Koweek, Yixuan Zheng, Elizabeth Susskind, Tyler Ruggles, Manoela Romano de Orte, Michael Mastrandrea, Theo Van De Sande.

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ROBIN MARTIN[2]
ANNA MICHALAK

[1] To February 28, 2019
[2] To January 11, 2019




« CARNEGIE SCIENCE »

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« THE DEPARTMENT OF PLANT BIOLOGY »

# Plant Science

First row (from left): Zhi-Yong Wang, Devaki Bhaya, Yunru Peng, Ngoc Ho, Kim Poon, Maria Lopez, Shouling Xu, Terri Tippets. Second row: Sue Rhee, Moises Exposito-Alonso, Naoia Williams, Justin Findiner, Emily Fryer. Third row: Evana Lee, Su Hong, Danbi Byun, Weichao Huang, Kangmei Zhao, Renee Weizbauer, Clare Tuma. Fourth row: Michelle Pazmino Cajiao, Frej Tulin, Karine Prado, Zhenzhen Zhang, Petra Redekop. Fifth row: Matt Evans, Flavia Bossi, Kanako Bessho-Uehara, Yuchun Hsiao, Jiaying Zhu, Rick Kim, Suryatapa Ghosh Jha. Sixth row: Kate Stevenson, Charles Hawkins, Chuan-Chih Hsu, Diane Chermak, David Ehrhardt, Veder , Cheng Zhao. Seventh row: Ismael Villa, Arthur Grossman, Jacob Moe-Lange, Bo Xue, Yanniv Dorone, Elena Lazarus, Kevin Radja, Navadeep Boruah, Efren Gonzalez, Chan Ho Park, Garret Huntress, Frederick De St Pierre Bunbury.

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[1] To October 31, 2018, retired
[2] To February 11, 2019, deceased



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